Chapter 2
Energy Infrastructure Planning in Cities and Territories, Quality Factors of Methods for Infrastructure Planning

The **objectives** of this chapter are

- Presentation of integrated energy planning in cities and territories (IEPCT), different phases, steps and general tasks
- Defining the energy infrastructure in cities and territories as a complex system complex system
- Defining characteristic types of IEPCT Use Cases for implementation in the following chapters
- Describing the model building process by different model terms and according to energy planning processes
- Providing the general requirements and quality factors of methods or methodologies supporting energy infrastructure planning in cities and territories

2.1 Introduction

The infrastructure in cities and territories is not only composed of a material component, but it also involves social and economic components. It is impossible to explain these components separately for long-range planning. Referring to critical infrastructure systems, Ouyang [1] states "These systems are not alone but interdependent at multiple levels to enhance their overall performance". Considering the whole, an infrastructure is the disposition of transportation, communications, fuel and energy, water supply, and institutions in the fields of education, health, and insurance [2]. Moreover, infrastructure in cities and territories needs to promote eco-system integrity and environmental regeneration, thus avoiding environmental degradation and providing economic and social goods and services [3]. The energy system in cities and territories is one of the critical elements of this infrastructure. In this book, energy infrastructure will be the focus of the discussion

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Table 2.1 Planning tasks and time horizon in energy industry

Planning category	Time horizon	Tasks and activities
Strategic planning	More than 10 years	Investment decisions for system replacement or extension
Tactical planning	3 years	Project risk management, …
	1 years	Budgeting, revisions, …
Operative planning	6 months	Hydro reservoir planning, …
	1 month	Financial optimisation, …
	1 week	Procurement planning, …
	1–3 days	Optimisation, …
	1 min	Regulation power, …

with consideration of the interdependency with other infrastructure elements and aspects.

Energy system planning by utility companies in a liberalized market can be divided into three different categories according to the task or activities and the time horizon. Table 2.1 shows the activities and time horizon in energy planning based on the discussion in [4].

IEPCT, which is the focus in this book, refers to long-term strategic planning. As stated in [5], "A local energy system consists of long-lived infrastructures (a planning horizon of 10–30 years and eventually up to 50 years), which does not lend itself to a quick modification or response."

The next section of this chapter will present an energy planning procedure based on a review that presents the tasks and activities systematically. Section 2.3 defines the energy system in cities and territories as a sociotechnical complex infrastructure. In Sect. 2.4 two representative Use Cases are defined for implementation in the next chapters. Modelling and the model formalisation process in the context of IEPCT are presented in Sect. 2.5. The overall requirements and quality factors, which can be used for evaluation and design planning support methods, are discussed in the Sect. 2.6. In the last section of this chapter, the main needs and review outcomes are summarised.

2.2 Integrated Energy Planning in Cities and Territories

At the beginning of the nineties, several events lead to changes in the energy market, and energy planning become more complex. These events include EU directives for the liberalisation of the energy markets, increasing environmental restrictions, an diverse interest of different people being involved in energy planning, a scarcity of fossil fuels, the use of intermitted renewable energies, and the increasing share of small distribution generations systems.

In an extensive review preformed in a previous study [6], a generic IEPCT framework was proposed for cities and territories. The planning is divided accordingly into different phases and sub steps. The overall planning procedure is presented in Fig. 2.1.

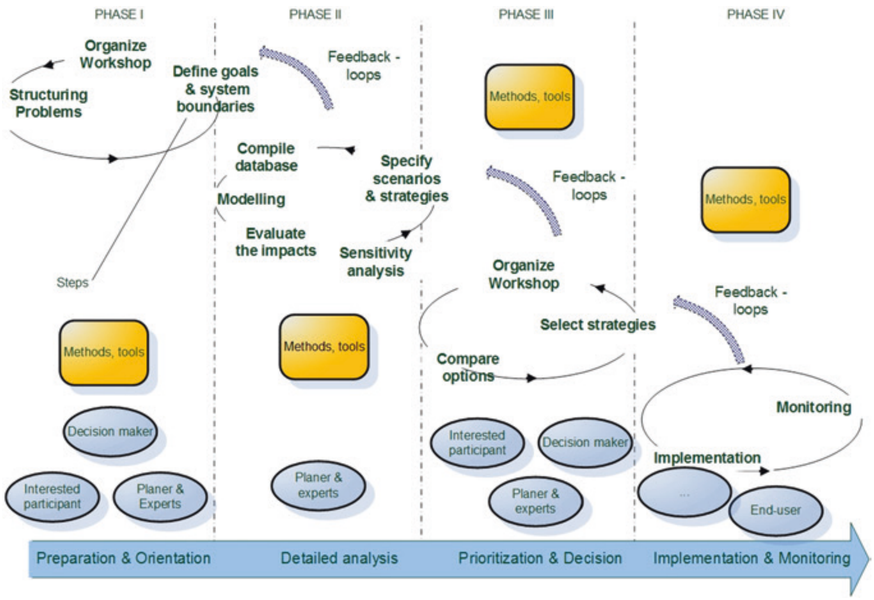

Fig. 2.1 General procedure of IEPCT (adapted from [6], used with permission of Elsevier)

From a methodological point of view, the planning processes are [6] 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

Different levels have been distinguished in the planning process [6]:

Participatory level, which describes planning participants
Process level, which describe planning tasks and activates
Methodological level, which shows methods and tools that are used to support different planning activities.

2.3 Energy Systems in City and Territory, a Sociotechnical Infrastructure

An integrated energy system incorporates energy supply and demand systems with many sub systems having different energy up- and downstream flows, services from primary energy to final energy supply to the customer. The energy supplier and user are not located anymore simply at the beginning and at the end of energy chain, respectively. Indeed, even small final energy consumers might become simultaneously electricity suppliers by using their own e.g. small PV system. The intermittent nature of renewable energy resources, energy market deregulation, and different interests and behaviour of different actors (supplier or energy consumer) make planning and modelling of such complex integrated systems very challenging and requires the appropriate modelling paradigm taking into account uncertainty issues. Integrated energy systems cannot be planned and modelled with only from the technical (point of) view because aspects, such as behavioural issues of the energy user or market requirements can have a strong influence on energy system design. Urban or regional systems have different activities, natural processes, culture, transportation or energy systems that are in different scales and have numerous interactions that make the modelling task highly complex. Accordingly, an integrated energy system in city or territory is a sociotechnical system. As defined in [7] "Sociotechnical systems are systems that involve both complex physical–technical systems and networks of interdependent Actors". It is a system of systems, an infrastructure involving different technical manifestations and social organizations [8].

Long range energy system in cities or territories can't be planned or analysed focusing only on local conditions within certain administrative zone or by pure geographic boundaries. Important parts of system like upstream flows of energy or national energy price is not considered in this case which might have high impact on planning and design of local system. How to consider this problem in planning and modelling is discussed in the Chap. 3.

2.4 Defining Typology of Application or Use Cases

The methods discussed in this book concern integrated energy planning in cities and territories (IEPCT) having more than 50,000 inhabitants for time horizons greater than 10 years. However, the planning process conditions can differ. In some situations, at the very beginning, an integrated model and plan is intended to be developed using one quantitative overall model, which is developed by a particular planning group. In another situation, the planning can begin with an integrated view for the city or territory development, without the possibility, or even the need, for developing an integrated single quantitative model. Separate models might be developed by different groups in different planning or project development time spans. It is also uncertain whether these separate models will be combined into one integrated, quantitative model in the near future. This leads us to define two general type of Use Case I and II.

2.4.1 Use Case I: Decentralised Multi-model Based IEPCT

In this case, the integrated plan is not implemented in one integrated quantitative model. Instead, different models might be developed by different teams separately with large project time lag. One model, for instance, might refer to the transportation sector, while another might refer to heating systems. These models are not integrated in one quantitative integrated model at the beginning of study and it is not intended to do so in some project time frame.

2.4.2 Use Case II: Integrated-Model Based IEPCT

Here, planning is based on one integrated model, which is developed in the foreseeable future, in a given planning time frame by a certain planning and modelling team. The integrated model can include different sub-models that are integrated in one model having different quantitative links e.g., a model for transportation, a cooling system or energy demand in industry.

Some mixtures of considered Use Cases are also possible but will not be considered here as separate cases.

2.5 Modelling in IEPCT

2.5.1 Models and Different Degrees of Formalisation

The modelling process can be divided into different degrees of formalization that are linked to the planning process. Similar to planning modelling process have different tasks and sub tasks which might be linked to the planning process discussed in the Sect. 2.2.

Following discussion and terminology definitions are provided here based on [9]. However, detailed information the interested reader can find in this reference.

Mental models are subjective, abstracted details of a specific world view of an individual mental world [10]. They exist only in the mental world of planning participants and are not interpersonal verifiable.

Conceptual models take into account the essential and relevant system elements and interactions for the specific problem and goal, descriptions of flows processes, system boundaries, aggregation level of analysis (temporal, spatial etc.), and a time horizon without mathematical description at this stage of modelling.

Between these two models are the expressed models, which are explicit descriptions of mental models. Mental models are expressed mostly in a verbal form.

Formal models (or site-specific model in [11]) are a numerical description of conceptual models that take into account natural laws, engineering, social and economic interactions. It includes all parameters, variables and their values. Formal models can not only be based on mathematical programming paradigms but also on other paradigms, such as agent-based simulation.

Computer models are encoded models in a computer program.

Calibrated models are the verified, corroborated models evaluated and tested by using different approaches, such as sensitivity or uncertainty analysis or calibrating some model parameters or functions against independent, exogenous data.

Applied models are implemented to support a decision maker's needs, such as analysis scenarios and assessment impacts of actions. These models present an opportunity for post auditing of the model: the model can be redesigned according to the decision maker's needs.

The link of different modelling and planning steps are presented in [9]. One of the main output of planning phase I is accordingly the conceptual model, which takes into account different study restrictions and planning participants needs. However, the conceptual model can be updated in future planning stages progressively. The formal model is usually developed in planning phase II and III. The computer model is usually not separate from the formal model and it developed simultaneously by implementing the formal model in computer code. The applied or final developed model ready in planning phase III. However, the modelling process continues in planning phase IV where the integrated plan is fleshed out into several programs and subproject. The integrated model can be divided into several partial models that support the planning activities in phase IV. The interrelation of modelling and planning activities are presented in Fig. 2.2.

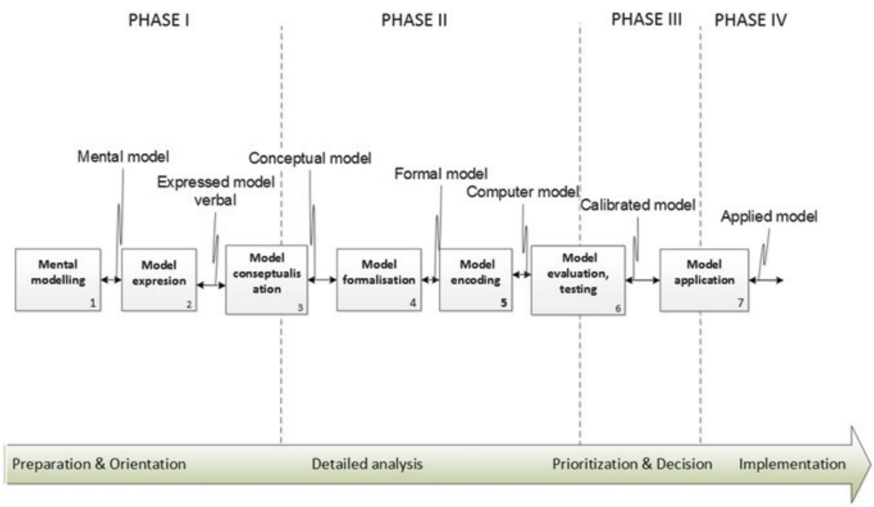

Fig. 2.2 IEPCT process and modelling steps (adapted from [9] used with permission of Elsevier)

2.6 Overall Requirements and Quality Factors of Energy Planning and Modelling Methods

A quality (from Latin qualities) is defined in [12] as "*The standard of sth when it is compared to other things like it; how good or bad sth is […]*". ISO 9000 defines quality as the "*degree to which a set of inherent characteristics fulfils requirements*". And requirement is defined as "*need or expectation that is stated, generally implied or obligatory*". ISO 9000 definitions will be implemented here. Certain requirements can have several characteristics or quality factors which measure fulfilment of requirement, such as when a requirement is "use less resources" for the implementation of a certain method. The measurable quality factors may be the "time" or "cost" required for implementing the method. Requirements and quality factors can be organised together in a hierarchical manner as shown in Fig. 2.3 and Table 2.2, where quality factors belong to the lowest level of measurable indicators. The structure and composition of the requirement tree can vary depending on study needs. As there are no predefined IEPCT planning standards, regulations or broth consensus known yet, the requirements and quality factors are defined based on a review of the empirical study's needs.

The overall quality of planning and modelling depends on several factors, such as implemented methods, experiences and competencies of planning participants, and conformity of the planning and decision-making procedure with existing laws. The planning atmosphere/venue can also play an important role. The quality of planning and modelling results/outputs are also a part of the overall planning quality. Planning and modelling under uncertainty, where planning output cannot be evaluated exactly, the planning process and used methods or methodology becomes the focus for quality evaluation [13]. These general factors provide the opportunity to see the extent of different aspects influencing the entire planning quality.

Fig. 2.3 Overall planning quality factors

Table 2.2 Requirements and quality factors of planning methods

Requirement	Quality factor	References
Technical considerations	Level of validity and legitimacy	[20–24]
	Generation of required outputs	See Chaps. 3 and 4
	Holistic	[4, 21, 23–31]
	Incorporation of qualitative and quantitative information	[32]
	Incorporation of different types of uncertainty	See Chap. 3
Organisational capability	Required time, money, expertise	[11, 24, 26]
	Flexibility	[27, 33–35]
Satisfaction by planning participants	Level of satisfaction with method	[20, 23, 24, 32, 34, 36]
	Level of satisfaction with results	
Knowledge discovering and learning	Level of avoidance of mental inertia and learning	[24, 25, 27, 37–43]
	Capability to identify and solve contradiction	
Collaboration support	Level of identification of conflicting interests	[24–26, 30, 33, 37, 44–46]
	Level of conflict resolution support	
	Level of interaction	

A framework for the evaluation of overall decision quality in the context of territory planning and management for resolving geographic boundary conflicts, not only for energy related tasks, is suggested by [14]. Quality of planning is divided into two major groups: quality of the decision process and quality of the decision outcome as shown in Fig. 2.3. The quality of the decision process is divided into three sub categories: quality of the decision procedure, quality of the decision unit (planning participants) and quality of the decision method [14].

The requirements and quality factors of planning and decision support methods suggested by [14] are examined in the context of IEP in cities and territories here. The need for additional quality factors is identified by reviewing the energy planning and modelling studies. The review has been performed using journals, such as Applied Energy, Energy Studies Review, International Journal of Energy Research, Sustainable Cities and Society, Renewable and Sustainable Energy Reviews, Energy, Energy for Sustainable Development, Energy Policy or Urban Studies. The keywords used in the review were quality factor or criteria, property, features, requirements, and proposed function of method. Books and technical reports were reviewed as well [15–19]. Very few studies discuss explicitly the requirements or quality factors of methods for IEP in cites or territories. However, it was possible to collect some factors (Table 2.2). The factors are structured hierarchically. The quality factors can be evaluated either quantitatively or qualitatively. In Chap. 5, these quality factors are specified and adapted for uncertainty analysis methods.

In general for rational choose, which is also the case for IEP in cities and territories three elements are important:

What do I want?—Goals and values of decision maker and planning participants
What can I do?—Initiatives, strategies or solutions to reach goals
What might happen?—Outcomes: Situations today and in the future.

Technical consideration

Technical consideration is the main functional requirement of methods or methodology implemented in planning. Three different quality factors can be used for classification this requirement.

Validity and legitimacy of method depends on different aspects. E.g. conformity of implemented method can be dependent on national or international norms like ISO-norms. This factor has formal character evaluating whether the method is conform to existing regulation or norms.

Generation of required outputs characterise whether the method or methodology produce required output for given planning and modelling step fully or partially. Let's notice that among others, some methods have to support generation of objectives and participants values, other methods have to provide numerical values of parameters of solution models, or outline the types and levels of uncertainty.

Holistic aspect refers in IEPCT studies the consideration of different aspect like economic, environmental or technical aspects, whole energy infrastructures taking into account different preferences of decision maker. Holistic view is particularly important for integrated studies for supporting long term sustainable territory development because it measures the possibility of method to appropriately incorporate different aspects and elements of infrastructure.

Incorporate qualitative and quantitative information: In long term interactive planning available information can be in quantitative e.g. statistical survey or qualitative like expert judgment, also preferences of decision maker, which are qualitative, need to be included in the analysis.

Incorporation of uncertainty is factor which shows whether all uncertainty aspect related to planning are considered and to what extent. These aspects are discussed in Chap. 5 more detailed.

Organisational capability

Organisational capability presents the aspects of flexibility and required resources for using the method or methodology.

Required time, money, expertise indicates how much time, resources or expertise is required for implementation of the method.

Flexibility of methods or methodology refers to whether it can be implemented and adapted according to different planning and modelling situations, Use Cases or phases without large effort e.g., using method or methodology in other conditions which requires less data, resources or expertise without large modification.

Knowledge discovering and learning

Level of avoidance of mental inertia and learning is an important factor that shows whether the method can help avoid mental inertia and support learning processes for the decision maker.

Identify and solve contradiction is another important aspect mentioned in some studies. Different categories of contradictions exist.

Satisfaction by planning participants

This factor reflects the decision maker's positive evaluation of the method. It is closely related to factor legitimacy or credibility discussed above.

Satisfaction with methods is a factor that can be evaluated directly in an empirical study testing or by using the method in real time. It measures the level of satisfaction with the method. Usually it depends on familiarity using the method.

Satisfaction with results is a factor indicating the level of satisfaction of method results by planning participants.

Collaboration support

Conflict identification and resolution is particularly important in an interactive planning situation with different stakeholders and planning participants. It determines whether the method can help identify conflicted interests and explicitly support conflict resolution.

Level of interaction is particularly important in group decision making as identified by [47]. The method has to support collaborative, fair and open decisions as opposed to manipulative decisions [14].

Quality factors using different methods together

The quality factors discussed previously refer to single methods. However, using different methods together for different planning tasks or phases is common. Therefore, additional aspects and rationales from mixed method research will be considered and discussed in Chap. 5 for designing a multi-method approach for uncertainty analysis.

2.7 Summary and Open Problems

The main conclusions of this chapter can be summarised as follow:

- The IEP in cities and territories is a complex, multi stage task that needs to take into account different aspects, such as environmental, technical or economic, different participants' interests and a complex, open energy infrastructure
- There are several tasks that have not been addressed systematically using methods or methodology yet, such as integrated modelling or uncertainty analysis. These issues will be discussed in greater detail in Chaps. 3 and 5

- Studies show that IEPCT in a conditions where no probability information about the states of environment is available or only some events probability can be roughly defined. IEPCT is performed in uncertain environment according to definition in Sect. 1.3.6
- IEPCT is a group decision-making procedure
- The planning and selection of plan has to be done taking into account multiple criteria in limited budget conditions
- IEPST is not flexible planning as defined in Sect. 1.3.6. It is rather rigorous planning for next 10–30 years, which does not lend itself to quick modification or response.
- None of the reviewed method can address all of the planning needs
- There are multiple requirements and quality factors which have to be considering when evaluating or developing of methods or methodologies to support IEPCT.

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