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Energy planning: a multi-level and multicriteria decision making structure proposal

Raphaële Thery · Pascale Zarate

Abstract Energy planning is a complex issue because of its multi-scale and multicriteria issues. In this contribution, a prospective analysis on the development of a multi-level and multicriteria decision-making structure dedicated to energy planning is developed. This analysis is based on an examination of the specificity of the energy supply chain as well as a state of the art aimed at classifying the issues solved according to the time horizon and size of the geographical area under consideration (models developed, the degree of accuracy of the information used, criteria taken into account).

Keywords Energy planning · Decision-making structure · Literature review · Multicriteria decision making · Multi-level management

1 Introduction

Recently, the population expansion, the industrialization of emerging countries and improvement of the quality of life has led to a steady increase in world energy consumption (Li 2005). At the same time, during the past decades, the development of

R. Thery · P. Zarate
Université de Toulouse, INPT-ENSIACET, Toulouse Cedex 01, France

R. Thery (✉)
Laboratoire de Génie Chimique (UMR CNRS 5503), 5 rue Paulin Talabot,
31106 Toulouse Cedex 01, France
e-mail: Raphaele.Thery@ensiacet.fr

P. Zarate
IRIT (UMR CNRS 5505), 118 route de Narbonne,
31062 Toulouse Cedex 09, France
e-mail: Pascale.Zarate@ensiacet.fr

a new generation of technology for energy conversion has been stimulated by the increasing willing to promote techniques economically competitive, environmentally friendly and socially acceptable, in other words, consistent with the requirements of sustainable development.

To deal with a wider energetic offer, actors playing a part at all levels of the energy supply chain (energy producers, policy-makers at the level of a country, a region or a local council, the end consumers as individuals and manufacturers) must cope with the problem of the optimal mix between the different available energy sources: this is the so-called *energy planning*.

In that context, this contribution intends first to describe a brief overview of studies recently published in the field of energy planning. Secondly, a characterization of the energy planning topic is proposed with particular emphasis on its multi-scale and multicriteria aspects. Several authors have already try to study these kinds of problems on a multicriteria point of view (see Girard and De Toro 2007). A classification of the problems encountered is then proposed: the purpose, the models developed, the methods of resolution used and the criteria taken into account are specified depending on the time horizon and geographical consideration.

Based on this study, a prospective analysis around a multi-level and multicriteria decision-making structure aimed at solving the energy planning problems is presented. As a conclusion, the scientific restrictions associated with the development of this decision-making structure are finally discussed.

2 General context of energy planning

2.1 Energetic system and supply chain

There are generally three states of energy, which depends on its stage of transformation (Fig. 1).

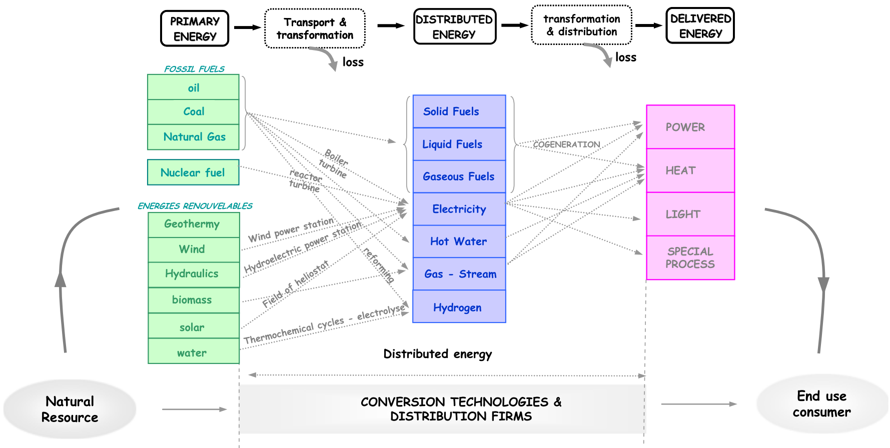

Fig. 1 Energy supply chain

- The *primary energy* refers to energy that has not been subjected to any conversion or transformation. Primary energy is contained in raw fuels and includes non-renewable (fossil and nuclear) and renewable energy (solar or wind).
- The *distributed energy* or *energy carrier* results from several transformations, but it is not yet finally in the form desired by the consumer. This is the form in which energy is transported for distribution to consumers (electricity, fuel).
- Finally, the *delivered energy* or *site energy* is the form of energy directly usable by the consumer (power, heat, light).

The *energy supply chain* is a triplet composed by a form of primary energy, a conversion technology and a form of delivered energy.

Currently, on a worldwide scale, the major part of energy demand is satisfied from fossil fuels (oil, coal, natural gas). A smaller part of energy production is provided by nuclear power plants and hydropower while a still smaller part is provided by renewable energy such as solar, wind and geothermal. However, the last few decades has permitted the development of new technologies for the conversion and distribution of energy such as fuel cells and bio energy (Sarlos et al. 2003). This diversification of supply, coupled with the existence of institutional conditions, geopolitical, economic and environmental strongly dependent on the regional and local characteristics makes the resolution of energy planning problems a complex one.

2.2 Energy planning: a complex issue

The energy planning consists in determining the optimal mix of energy sources to satisfy a given energy demand. The major difficulties of this issue lies in its multi scales aspect (temporal and geographical), but also in the necessity to take into account the quantitative (economic, technical) but also qualitative (environmental impact, social criterion) criteria.

2.2.1 A multicriteria issue

During the last decades, the energy planning was only guided by technical and economic criteria aspects. However, the current socio-economic context tends to other criteria such as:

- *environmental criteria*: emissions, depletion of natural resources, pollution,
- *safety criteria* and *health criteria*,
- *social criteria*: comfort, quality of service,
- *geopolitical criteria*: security of supply, decentralization of energy production.

Among these criteria, some of which are clearly antagonistic, must be considered jointly. In addition, they must also remain consistent with the regulatory constraints which are often specific to each country and often changing very quickly over time.

2.2.2 A multi-scale topic

Table 1 provides a non-exhaustive summary of the issues addressed in the literature concerning energy planning. It is clear that, from this classification, the type of

Table 1 Energy planning: state of the art

		SHORT TERM Horizon : 1 year Period : day, week, month …	MEDIUM TERM Horizon : 1 to 15 years Period: year	LONG TERM Horizon: more than 15 years
GENERAL PROBLEMATIC	**Purpose**	Ensuring optimal coverage needs with the existing conversion, transport and distribution equipments	Ensuring optimal coverage needs on a longer horizon. Considering the possibility of development of new energy infrastructure	Same problematic as in the tactical level but in a context in which the potential social, economic and technological changes are much more uncertain
	Kind of possible action	Emergency measures	Management Development of infrastructures	Development of infrastructures Promoting/Restricting of given technologies
DEMAND FORECASTING	**Key Factors**	*Uncertainty and Risk* Climate Change: heat wave, cold waves Variation of the price of energy Consumers behaviour	*Smoothing the changing demand -trends* Demographic evolution, Socio-economic changes Technical progress	*Significant changes of the social, economic and technological context* Necessity to include the likely disruption of some primary energy resources
	Model	*Extension of trends existing at the beginning of the study period* ❑ Chronological Time Series ❑ Neural Networks (Kalogirou 2001)	*Estimation which depends on the horizon :* *One Year*: Same approach as for the local level *Longer periods*: econometric, techno-economic method	*Exploratory analyses based on the development of different kinds of scenario* General equilibrium model (Frei et al. 2003)
OFFER MODELING	**Purpose**	***Modeling an existing system***	***Modeling a system which could be modified***	***Modeling a system which could be modified and integrating projection about future technologies***
	Local level	*1 energy conversion unit* **Model:** phenomenological or behavioural **Variables:** operating parameter of existing unit (Oliveira Francisco et Matos, 2004)	*1energy conversion unit* **Model:** phenomenological or behavioural **Variables:** Design of existing or future units	
	Cluster	*Several energy supply chains* **Model:** flow graph modeling for representing energy flux from the natural resource to end-use consumer (cf fig 4): **Example:** MODEST (Henning et al. 2006), (Sodermanet Petterson 2006) **Variables:** energy flow at each level of the graph	*Several energy supply chains* **Model:** flow graph modeling for representing energy flux from the natural resource to end-use consumer (cf fig 4): **Example:** EFOM (Cormio et al. 2003), EPOM (Farid et Khella1997) **Variables:** Energy flow on each level of the graph	*Several energy supply chains* **Model:** scenarios(transitive, descriptive, normative, Contrasting) **Variables:** decisions (not necessarily quantitative decisions) Concerning the development and the promotion of some energy conversion technologies **Examples**: (Beccali et al. 2003) (Haldiet Vlachantonis 2001)
	Territorial level (continent, country, region)			
RESOLUTION TOOLS		Linear programming (MILP, LP) Non linear programming (MINLP, NLP)	Linear programming, dynamic programming Multicriteria decision making	Multicriteria decision making (Pohekaret Ramachandran, 2004)
CRITERIA	**Cost**	∗∗∗ (always)	∗∗∗ (always)	∗∗∗ (always)
	Environ.	∗ (seldom)	∗ (seldom)	∗∗∗ (always)
	Other			Technological maturity, social acceptability, safety…

information taken into account, including energy demand, the models adopted, the criteria and the expected results strongly depend on the time horizon and the geographical dimension considered.

- Influence of the time horizon

Traditionally, the resolution of energy planning problems can be classified according to three temporal issues: the short-term (hours, days, months, till the year), the medium-term (from the year to 10 years) and the long-term (beyond 15 years). It seems clear that the size of time horizons strongly affects the nature of the data used and the actions to be implemented.

A short-term forecasting of future energy demand is mainly based on the analysis of historical and extrapolating load curves under different types of hazards (climatic, social, economic). The purpose is to ensure the reliability of service required by exploiting the reactivity of existing energy systems. Over the long term, the purpose is mainly to anticipate changes in demand by developing new infrastructure or promoting new technologies keeping in mind constraints concerning the turnover rate of installations. In that context, the environmental and technological criteria appear to be essential. In addition, the foreseeable increase in demand is matched by the political willing to reduce consumption. This point makes the forecasts all the more uncertain.

- Influence of the geographical dimension

The structure of the models used and the criteria considered also differ significantly depending on the geographic area. In this context, Hiremath et al. (2007) suggest the following breakdown: the *overall level* refers to the energy system on a global scale. The *national level* concerns the energy system of a continent or nation. The *regional level* concerns the energy system of a city or an entire city (also called *cluster*) intending to share their resources and equipments dedicated to energy conversion. In Table 1, the national and regional levels are only raised, the overall level corresponding to a geopolitical vision more than a scientific vision. Furthermore, a *local level* referring to the study of an energy conversion unit has been introduced.

At the national level, the range of possible technologies is large, but at the cluster level, the choices are more limited because they must be adapted to the particular natural resources locally available. On the other hand, the concept of *decentralized energy production* that emerging tends to promote the development of reduced capacity equipment, closer to the consumers and spread over the territory at the expense of high capacity power station (Söderman and Pettersson 2006; Hiremath et al. 2007).

The analysis of this table enables to highlight the large number of studies already published in the area of energy planning. It should be noted that, although there are strong interactions between these different levels, the issues raised are often treated as independent problems.

A major challenge concerning energy planning then relies on the design of decision-making structure based on a clear understanding of the energy systems considered, but also on a detailed analysis of the interactions between the different levels in the decision process. Regardless of the type of decision-making process used (hierarchical or distributed), a global strategy aimed at ensuring consistency between the successive decisions taken at each level is necessary.

3 Multi-criteria and multi-level decision making strategy for energy planning

The previous section showed the multi-criteria and multi scales aspects for energy planning but also the strong relationships existing among all actors implied in the energy supply chain. Based on the proposed classification (see Fig. 1), a multi level decision making strategy is proposed.

3.1 The proposed decision making structure

The decision making structure, that we propose to implement, is based on a space/time scales represented in Fig. 2.

Based on this scale, three levels of decision making are identified. These three levels are well known in the Management field and for Decision Support Systems developed for Manufacturing Systems (Production Plant).

This decision making structure is based on a hierarchical structure associated to data aggregation mechanisms and decision making desaggregation. The decisional process, the role and the objectives of each level are represented in the Fig. 3. Each level is built on a specific model satisfying a set of constraints aiming a precise objective and based on its own models (temporal horizon adaptation, level of data aggregation, criteria taken into account etc …). Based on a top-down approach, the decisions made at a specific level become constraints for an inferior level.

The role for each level in the whole decisional process is detailed afterwards.

3.1.1 The strategic level

For the proposed approach, this level aims to establish an energy planning on a long term point of view, on a territorial scale. Thanks to an estimation of the demand evolution for the delivered energy (electricity, hot water, vapour) on several decades, this level must allow one to determine for each potential energy chain (existing energy

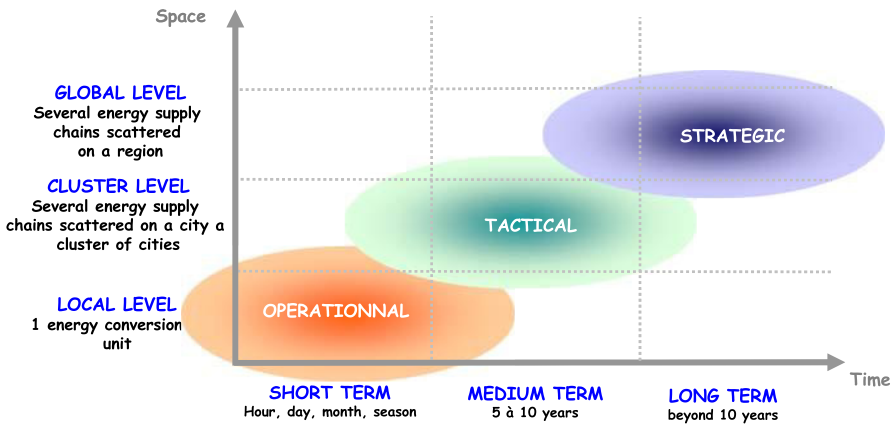

Fig. 2 Three levels of decisions considered for the energy planning

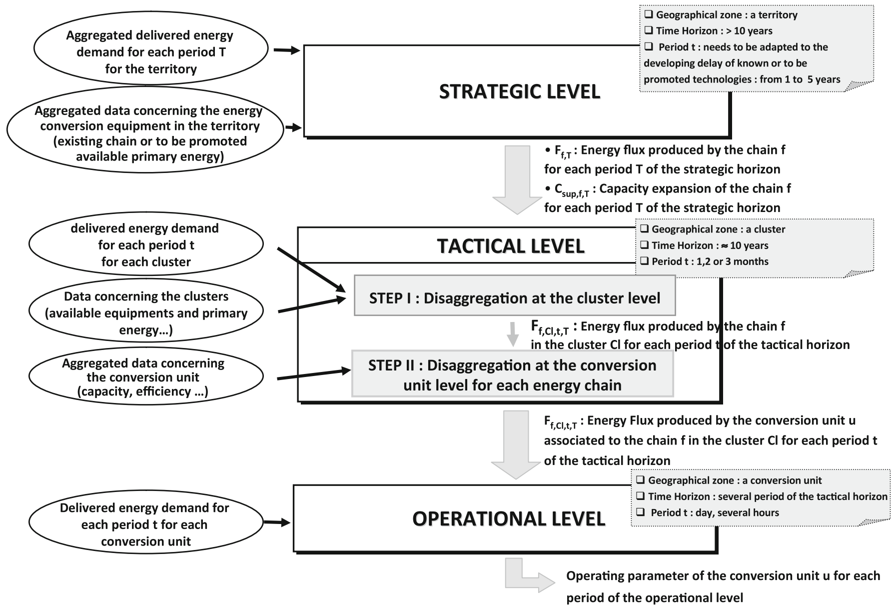

Fig. 3 Multi-level decision making structure dedicated to energy planning

chain or to promote), the evolution of energy quantity to produce for each period (year, decade depending of the temporal scale studied).

This level will be based on the evaluation of several energetic scenarios such as projections on the evolution of the demand, of the social and political context and of the production systems.

3.1.2 The tactical level

This level aims to establish energy planning for a cluster on a medium term based on strategic decisions made in the superior level. A cluster is defined as a set of several energy producers and a set of consumers (individuals, local authorities, enterprises) associated in order to share their energy production equipment. At this level, for a given set of suppliers and end use consumer, the energetic system could be represented in an aggregated form in Fig. 4. This type of system can be modelled as a flow graph where each node represents an energy source, a producer or an energy consumer. The edges represent the energy flow (primary energy, distributed energy, delivered energy) exchanged among each node. A path in this graph represents an energy chain.

The articulation between the strategic level and the tactical level is made up two desaggregation steps:

– the first step consists in a spatial desaggregation aiming to determine, for each period of the tactical horizon, the assignment of energy flows coming from each energy chain in each cluster of the considered territory. Each cluster presents its own energy demand, its own production system, its geographical constraints or then its natural resources. Nevertheless, as shown in Fig. 4, several interactions

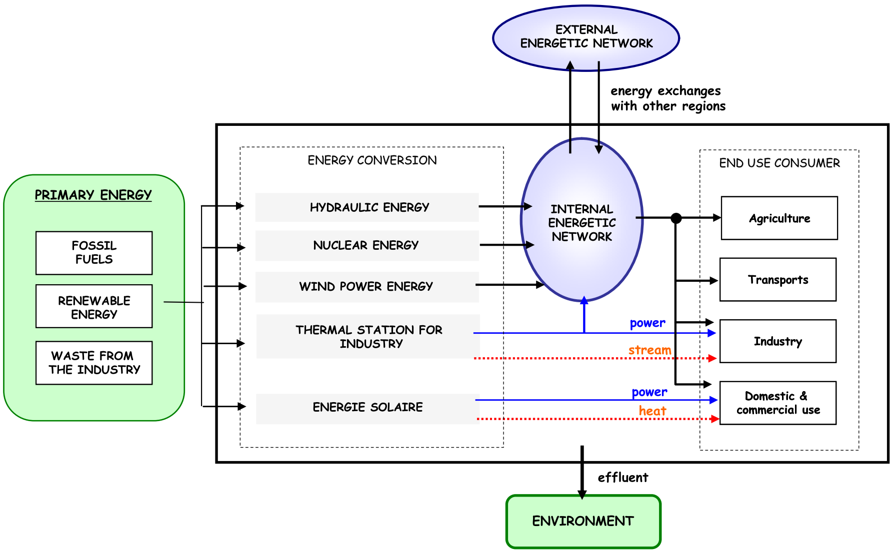

Fig. 4 Modelling of an energy system at a cluster level (Cormio et al. 2003)

among clusters exist because of energy conversion systems shared between several clusters. These interactions are then modelled by an in flow or/and an out flow depending of the case.

– the second step of desaggregation attempts then to determine the energetic flows coming from the different conversion units associated to each energy chain. Each conversion unit is distinguishable from each other by its production capacity, its efficiency or then the distance between itself and the end use consumer.

3.1.3 The operational level

Knowing the quantity of energy to produce for one conversion unit in one cluster (determined by the tactical level), the operational level aims to plan on a short term perspective the energy production for this unit evaluating its optimal operating parameters.

In this case, the energy chains would be modelled in a more precise way thanks to phenomenological models of process as those used for the modelling of the power station (see Oliveira Francisco and Matos 2004) or the behavioural models based on for example neuronal networks or then on Bond Graph (see Bouamama et al. 2006; Jebaraj and Iniyan 2006).

4 Conclusion

This problematic is developed through studies aiming to analyse and formalise decision making process for complex systems. If the global system decomposition seems to be a mean to handle this complexity, it also implies several problems to solve linked to the decision making successive refinement. The research works introduced in this paper are oriented on three directions.

Firstly, the multi scale aspect of the problem leads to the necessity to adopt heterogeneous models (aggregated models, detailed models, knowledge base models, mathematical models). An important issue must be underlined aiming to select the most adequate models or methodologies. For the strategically level, it seems interesting to use a multi-criteria decision making methodology as Electre (Roy 1985). For the inferior levels, mathematical, stochastic or hybrid optimisation methodologies can be used.

Another issue must be underlined aiming to select the criteria to take into account at each level and their performances. The cost criterion is obviously the main one but we propose to integrate other criteria. In a first time, an environmental criterion, based for example on the process cycle life analysis (eco-design) (Azapagic and Clift 1999), could be used. Nevertheless, several other criteria like for example security or flexibility could be efficient at the operational level.

Finally, this kind of decision making process could be efficient only if a decision is made at a specific level assuming the coherence with the constraints coming from the inferior level. A fundamental issue of these works aims to adopt a decision making process insuring a global cohesion.

Among the possible solutions, the following are the most well known:

– use of iterative procedures based on the continuum refinement of the evaluation mode of criteria or constraints taken into account in each iteration;
– formulate constraints, able to limit the possible generated solutions domain for keeping only those for which the feasibility at the following level will be guarantee. A formal representation of these interactions through a model could point out relationships among these units which do not appear in the initial models and could determine in a systematically manner the researched conditions.

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