An integrated framework to support sustainable electricity planning

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Abstract

The changes in the electricity sector along with the need for sustainable development required traditional electricity planning to expand beyond pure financial analysis and even beyond direct environmental impact analysis. The electricity planner has now the task of designing electricity strategies for the future with the view of enhancing the financial performance of the sector while simultaneously addressing environmental and social concerns. However, the integration of the relevant dimensions of sustainable electricity planning poses important challenges to researchers. In addition, to properly deal with the increasing use of renewable energy sources of variable output, traditional optimisation models must be able to integrate the short term operational planning and dispatching process with the long range planning models. This paper proposes a new framework to sustainable electricity planning, based on optimisation models for electricity power planning combined with participatory methodologies for addressing the social dimension of the problem. The effective implementation of this framework is demonstrated for a real case study based on the Portuguese electricity system. The research started from the presentation of electricity generation scenarios for 2020 drawn from a mixed integer linear optimization model. These scenarios were then characterized under different social, economic and environmental impacts, and evaluated according to a multicriteria procedure based on experts' inputs.

Keywords: Electricity planning; Optimization model; Participatory methodologies.

1 Introduction

The electricity planning process needs to rely on a formal approach to the assessment of the overall financial, environmental and social outcome of each particular scenario. This work addresses this matter and deals with the complexity of the interdisciplinary process surrounding electricity planning. The paper presents a research project under execution, based on a methodology combining different techniques and comprising both mathematical evidence and value judgment considerations in order to give a contribution to the sustainable central electricity planning problem. The structure of the paper is as follows. Section 2 deals with electricity planning and Section 3 presents a short review of the electricity planning models. In Section 4 a structured methodology for sustainable electricity planning is proposed. Section 5 describes the implementation of the proposed framework to the Portuguese electricity system. The main conclusions are summarized in Section 6.

2 Electricity planning

Electricity power planning is, using the definition of Hobbs (1995) "the selection of power generation and energy efficiency resources to meet customer demands for electricity over a multi-decade time horizon". This author presents three reasons for the increased complexity of the energy planning process: the increasing number of options, the great uncertainty in load growth, fuel markets, technological development and government regulation, and finally, the inclusion of new objectives other than cost. In fact, the changes in the electricity sector along with the need for sustainable development required traditional electricity planning to expand beyond pure financial analysis and even beyond direct environmental impact analysis. The increasing use of renewable energy sources (RES) in electricity systems adds additional considerations to the traditional planning models, in particular the need to take into account: (i) their frequent priority access to the grid system; (ii) the impacts that technologies of variable output, such as wind energy can have on the overall operation of the electricity system and (iii) the public attitude towards these technologies. In addition, the central electricity planning process based on a single decision maker is no longer acceptable, and the importance of examining tradeoffs among objectives is now well recognized. Considering the three dimensions of sustainable development the importance of the social aspect in the decision process has significantly increased.

The central planner has now the task of designing electricity strategies for the future with the view of enhancing the financial performance of the sector while simultaneously addressing environmental and social concerns. Thus, the planners must deal, not only with variables that may be quantified and simulated, but also with the social impact assessment. As Bruckner et al. (2005) note this is an ever changing field, depending on aspects like policy issues, advances in computer sciences and developments in economics, engineering and sociology.

Hobbs (1995) classified energy planning according to the time length and objectives, including for example resource planning, long range fuel planning, maintenance, unit commitment and dispatching.

The centralized long range resource planning is mainly concerned with socio-economic policy making. It is dedicated to decision-making on the choice of technologies, given objective functions and some constraints. The decision model used identifies which technologies should be chosen to get as close as possible to the objective (Boulangera and Bréchet, 2005). Frequently there is more than one objective to consider and there is a plurality of decision-makers with different preferences and expectations. On the other hand, the mid and short term planning mainly consist of making production decisions aimed at meeting demand with an adequate security level and taking into consideration cost and emissions objectives. As the time horizon gets lower, the accuracy of the forecasts available to the planners gets better and new decisions must be made in order to accommodate possible changes and even regulate production in real time. This type of planning assumes as a given input the technologies available in each period and is based on the specific characteristics of the generators in the system.

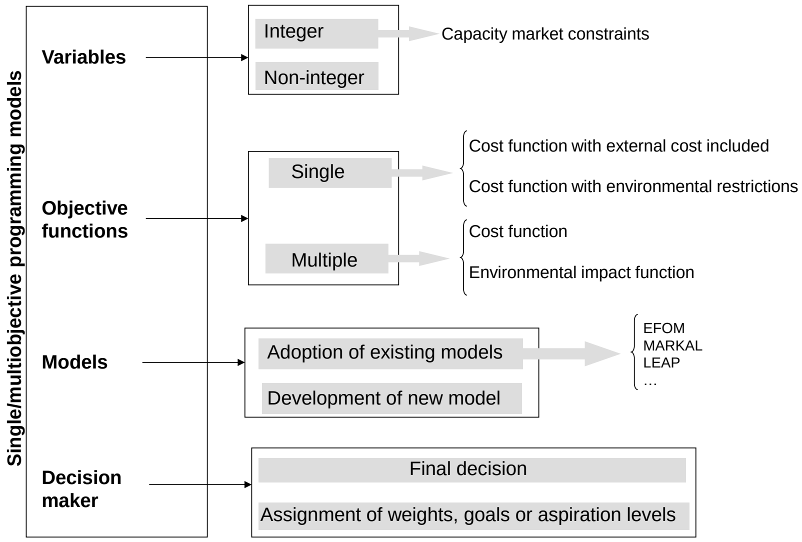
3 Electricity planning models

The electricity planning process has been addressed by a large number of authors, proposing different approaches and models to solve these problems. Most of these approaches include diverse multicriteria tools, expressing each criterion in its own units, or are based on some kind of cost benefit analysis, in which environmental criteria are expressed in economic terms. The process frequently requires the planner to work with quantitative and qualitative information. However, continuous models focus mainly on the cost and economic dimensions of the problem. Some of the less quantifiable issues associated with the social impacts of electricity generating activities have been covered by multicriteria models, using well recognized methods like the ones from the outranking family such as the Analytic Hierarchy Process (AHP), or by the economic valuation of externalities like the ExternE study (European Commission, 2003).

The literature, for long has been debating the planning models available and providing some examples of application. Ferreira (2008) reviewed recent papers proposing different approaches to electricity planning and distinguished two broad methodologies: Single or multiobjective optimization procedures and discrete models.

3.1 Single or multiobjective programming models

Single or multiobjective programming models are based on the mathematical description of the electricity systems. Figure 1 summarizes possible approaches used in the literature.



EFOM-Energy Flow Optimization Model MARKAL- MARket Allocation; LEAP- Long range Energy Alternatives Planning System

Figure 1: Single or multiple objective models for energy planning.

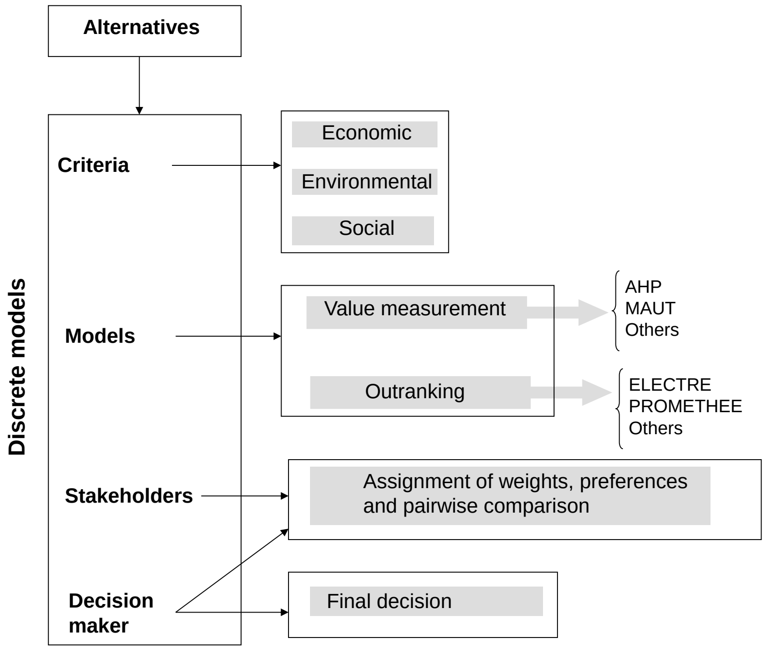
Most of these studies are based on complex mathematical models backed up by powerful software systems. They have the advantage of combining a large number of constraints and variables described by mathematical functions. This means that no initial description of the possible scenarios or plans is needed to be presented to the decision maker. The outputs of the model are already optimal plans in regard to the objectives considered, obtained from optimization procedures based on the supplied data and on the functions described.

Optimization models may include real and integer variables and include one or more objective functions. The use of integer variables takes into account the discrete nature of the capacity of new plants available in the market. When a single objective cost function is considered in the model, the environmental impacts are usually included in the function as external costs or are included in the model as constraints. The models used may adopt an existing model such as MARKAL, LEAP or EFOM-ENV (see a description of these and other models in http://www.energycommunity.org/) adapting it to each particular case, or may rely on the development of individual models for a region or for a segment of the energy sector like electricity power planning. The obtained plans, representing different tradeoffs among the distinct objectives are then presented to the decision makers for the selection of the final solution. Nevertheless, some models already employ a participative approach, including the decision maker on the assignment of weights or aspiration goals to the considered objectives. However, the more subjective impacts frequently associated with the social dimension of the energy planning problem are not treated explicitly. The social impacts are assumed to be included in the monetary values assigned to the externalities or are not brought into the analysis at all.

According to Loken (2007) the main advantages of the single or multiobjective programming models include their low subjectivity, the straightforward procedure well understood by decision makers and the possibility of using linear programming solvers. However, the complexity of the models is a considerable drawback, along with the need to assign weights to different objectives and the difficulty of integrating non quantitative criteria. Lehtila and Pirila (1996) call attention to major problems of the optimization models, including the need to keep the model size manageable, the fact that small variations in input parameters can sometimes lead to large variations in the solution and that the most attractive alternatives tend to dominate the solutions, even if the cost differences are low. Also, Jaccard et al. (2003) report that an optimization model calculates technology shares on the basis of winner-take-all and that small change in costs can lead to dramatic changes in outcomes. The solution found is optimal from the point of view of all information available to the model, disregarding non quantitative aspects which may be difficult to include in the model as constraints.

3.1 Discrete models

Discrete models generally recur to the comparison of scenarios, technologies or projects, based on value measurement and outranking methods. Figure 2 summarizes possible approaches used in the literature.



AHP- Analytic Hierarchy Process; MAUT- Multi-attribute Utility Theory

Figure 2: Discrete models for energy planning.

The studies based on discrete models start by identifying a number of possible energy plans or strategies. These plans are then characterized according to a set of criteria and different methods may be used to aggregate all the information in a final ranking of the available alternatives. The models often deal with the economic, environmental and social dimensions of the problem. Depending on the model used, a final score may be obtained for each alternative either dimensionless or with monetary translation or the final output may be the preference ranking of the alternatives or the proposal of the best alternative. Discrete models often call for the stakeholders and/or the decision maker involvement throughout the process to assign weights, to indicate preferences or to participate in pairwise comparisons. The participatory multi-criteria analysis can be resource intense, but it allows decision-making based on a robust and more democratic process, addressing uncertainties, acknowledging multiple legitimate perspectives and encouraging social learning (Kowalski, 2009).

Discrete models have the advantage of presenting to the decision maker a set of detailed characterized alternatives, which may make the decision process clearer than when complex mathematical functions are involved. Also, these models have the ability to include both quantitative and qualitative criteria in the same framework. Methods such as AHP or outranking are claimed to be simple and easy to understand (Loken, 2007) and are frequently used with discrete models. However, energy problems are frequently very complex involving a large number of alternatives and criteria, which represents an important drawback to these methods.

In the case of electricity power planning, the large number of possible mixes of electricity generation technologies gives rise to an extensive number of alternatives, thus requiring special attention on the selection of the feasible electricity plans to be analyzed under discrete models. These alternatives frequently come from government organizations or from the company in charge of the management of the electricity system, may be proposed by experts or stakeholders or may be developed by the researcher taking into account the specific characteristics of the electricity system under analysis.

Corroborating studies such as Hobbs and Meier (2003) and Loken (2007), Ferreira (2008) concluded that a combination of more than one models and methods in the planning model could give an effective contribution to the design of sustainable energy scenarios for the future, accommodating the economic, social and environmental dimensions and simultaneously addressing the impact of electricity generation sources of variable output, as wind power.

For long the literature, has been debating the planning models and underlying methods available and providing some examples of application. A detailed analysis of the subject may be found in studies such as Loken (2007), Pohekar and Ramachandran (2004) or Kowalski et al (2009), where the authors review a large number of publications on the use of multicriteria decision making for energy planning. Also Hobbs and Meier (2003) present what they call a "representative sample" of multicriteria decision making applications to energy planning and policy problems. Huang et al. (1995), present a comprehensive literature review on decision analysis on energy and environmental modeling, including studies published from 1960 to 1994. Greening and Bernow (2004) collect some examples describing the application of several multicriteria methods to energy and environmental issues. Diakoulaki et al. (2005) analyzed a large number of publications addressing the use of multicriteria methods to energy related decisions and Jebaraj and Iniyan (2006) review several energy models including planning and optimization models, among others .

4 An integrated framework to sustainable electricity planning

There is no single way to proceed with an energy project evaluation and the energy planning process. It clearly depends not only on the objective of the work but also on practical aspects like the available data and time, the specific characteristics of the region and the members of the team. As Georgopoulou et. al. (1998) state "energy planning should be seen as a complicated task to be performed in an ill-structured environment through a hardly prescriptive procedure". An approach to the sustainable central electricity planning problem is proposed, combining different techniques and involving several integrated steps, reflecting both mathematical evidence and value judgment considerations.

- The process must rely on a detailed analysis of the electricity system under study, including:
  - The characterization of the present situation of the electricity system should be the first stage, as the process is based on an incremental approach.
  - The characterization of the future prospects of the electricity system (namely demand and electricity generation technologies).
  - The description of the legal and technical restrictions expected for the planning period.

- The economic and environmental dimension of the problem does not directly involve the decision makers' participation but rather includes:
  - The identification of all relevant costs and environmental impacts.
  - The monetization of the tradable environmental damages.
  - The development of an optimization procedure for detailing future plans for the electricity system, including all the criteria capable of being described by mathematical functions.
- Given the distinctive character of the social dimension, it cannot be addressed with the same analytical toolbox as the environmental and economic ones (Lehtonen, 2004). The information

developed through the optimization procedure is enriched with the perception of the decision makers, including:

- The identification of the relevant social impacts.
- The development of a framework for collecting information and value judgments from the different agents.

- The integration of these judgments into the decision process.

From the application of the outlined process, in respect to a selected number of feasible electricity generation plans, the decision maker should be given cost, total CO2, social impact assessment and external dependency of the electricity generation sector, from which a final decision may be made.

5 The SEPP-Sustainable Electricity Power Planning project

The work described here is included in the SEPP (Sustainable Electricity Power Planning) project, funded by the National Foundation for Science and Technology and involving researchers from University of Minho and Faculty of Economics of Porto. This research project started in June 2010 and it is expected to be finished by June 2013 and represents a real-case application of the proposed framework. This section aims to focus mainly on the methodology implementation showing how the proposed steps were carried out. The SEPP research strategy includes three main areas:

(i) Optimization models for electricity planning based on mathematical formulation of models and search for optimal scenarios.

(ii) Participatory methodologies for the evaluation of social acceptance of different electricity generation technologies.

(iii) Integration of the collected information and proposed models and methodologies in a new framework to design and evaluate electricity generation scenarios.

The project is expected to result in important contributions to the international scientific knowledge, to energy decision makers and to companies operating in the electricity market. The research team recognized major challenges associated with sustainable electricity power planning and proposes an integrated model to deal with these challenges, combining mathematical, engineering, social and financial knowledge.

5.1 Scenario construction

This phase of the research was based on the formulation of multiobjective mathematical models for the incremental electricity planning in Portugal for a ten years period (2011-2020), departing from the 2010 situation. Their formulation involved: data collection from reports, legal texts and documents published by companies operating within the sector; the translation of the technical and legal requirements into mathematical functions (constraints); and the formulation of economic and environmental objectives which are also translated into mathematical functions.

The model resulted in mixed integer linear optimization problems, assuming average operating conditions for all power plants. The model was translated in a GAMS (General Algebraic Modeling System) code and a regular optimization procedure was conducted. The final results were a set of optimal electricity power plans for each model, detailing: the electricity generation schedule for the next ten years, the monthly plans for electricity production, the yearly plans for generating capacity expansion, the total cost and the level of CO2 emissions. A full description of the model is available on Pereira et al. (2011).

5.2 Social analysis of the scenarios

Expert judgment of direct and indirect impacts is relatively quick and cheap and it can be used in applications like collecting data, developing alternatives from the strategic policy level to the detailed site level, analyzing and ranking them, predicting impacts, and suggesting mitigation measures (OCDE, 2006). Studies such as Alberts (2007) demonstrated that when the questions or matters under analysis are those of high uncertainty and speculation, a general population or sample might not be sufficiently knowledgeable to answer the questions accurately. Seeking inputs from technical experts is then easier and less resource consuming than to seek consensus from all stakeholders in a topic such as electricity planning.

As such,, this phase of the research project included the following steps:

- Construction of the scenarios, as described in section 5.1.
- Interviews with experts to clarify the relevant impacts of electricity generation technologies in Portugal. From this logic models were drawn for each technology demonstrating the short, medium and long term impacts, as described in Ribeiro et al. (2011).
- Characterization of the scenarios under each impact (translated as objective criteria), focusing in the results for 2020.
- Multicriteira evaluation of the described scenarios based on inputs from a group of experts. The inputs were collected both by email and in face to face interviews. The results of this multicriteria evaluation are described in Ribeiro et al. (2012).

The construction, characterization and evaluation of the electricity generation scenarios took about 12 months. The results demonstrated that the multicriteria evaluation of the scenarios is far from being a consensual matter. Nevertheless, important conclusions could be drawn, namely: cost remains by far the most important objective for most experts followed by the quest for energy independence of the country. This is not an easy trade-off in Portugal, as those are absolutely diverging objectives. The least cost solutions are the ones with higher fossil fuel share which in turn makes these solutions the ones with higher importation levels. This is in fact one of the most important reasons for the difficulty on achieving consensus among experts. Also, the scenario construction model demonstrated the need to combine long term energy expansion strategies with short-term electrical power generation scheduling, for an hourly time step during one year horizon planning, evaluating the impact that the hydro-wind power combination strategies may have on the efficiency of thermal power plants.

5.3 Work in progress

The research project is now proceeding with the development of optimisation models able to integrate the short term operational planning and dispatching process with the long range planning model. This is expected to make a contribution on properly dealing with the impact that renewable energy sources of variable output have on the electricity system management. This new approach creates additional complexity and must be supported by the development of robust optimisation procedures that may deal not only with non-linear mixed integer models fully characterising mixed hydro-thermal-wind (and even nuclear) systems, but also able to combine optimal decisions in different time frames plants.

As for the social dimensions, the study will proceed beyond the first expert based experience, aiming to analyse the social acceptance of the different electricity generation technologies, identifying major sources of concern and geographical patterns. This study will provide information that can make an effective contribution to the social acceptance of electricity generation plans, minimising the social controversy and unexpected projects failures. For this, a field implementation of a large scale survey is being prepared aiming to assess the social acceptance of RES technologies and the evidence on NIMBY feeling, concerning RES in Portugal. The results gathered from the large scale survey will contribute to understating different attitudes between social groups and different regions. In addition, the work is also focusing on local and regional impacts of RES technologies, resourcing to interviews with local stakeholders.

6 Concluding remarks

This paper presented the foundation of the research project SEPP (Sustainable Electricity Power Planning). An overview of the key elements of sustainable electricity planning was provided. Central electricity planning models described in the literature were presented, demonstrating the complexity of the process and the possible approaches to the planning problem in order to design a methodology able to combine technical, social, environmental and economic evaluations. The literature review demonstrated that the integration of the relevant dimensions of sustainable energy planning poses important challenges to researchers. It is clear that the integration of the social criteria issues on the evaluation of future electricity plans, although being fundamental, is not an easy and consensual task and merging mathematical evidence based on optimization procedures with value judgments seems to be fundamental.

The results obtained so far allowed to conclude that cost remains as the fundamental barrier to RES growth in the electricity system. The optimization procedure indicated that as the CO_2 objectives become more restrictive, replacing coal by natural gas, in general, still remains as a more interesting option from the cost point of view. Wind power contribution only increases significantly for highly environmentally constrained solutions. Also, aggregating the results of the multicriteria procedure, cost was considered the most important criterion; therefore, it stands as the major obstacle to the implementation of more renewable energy scenarios in the electric sector.

Future results of the project are expected to give important contributions to central decision makers, supporting also investment decisions of companies operating in the electricity generation sector.

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