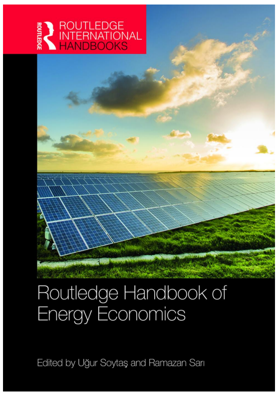

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The use of foresight in energy policy

Erik Laes

1 Introduction

In view of long-term energy or climate mitigation goals, energy policy frequently makes use of technical-economic programming models of energy systems and to compile energy/environment scenario evaluation, in order to evaluate costs and benefits of different strategic options. It is certainly no easy task to make such long-term (frequently 30 years or more) evaluations in an environment determined by complex interactions between technological, economic, social, cultural and institutional spheres. Evaluation nevertheless presupposes that these evolutions can be understood, described and integrated in a scientific way. Numerous techniques and approaches are in use, drawing on different scientific disciplines (e.g. statistics, economics, psychology, marketing, organizational theory, etc.). Broadly, these are referred to as methods of scientific foresight (sometimes also referred to as 'future studies'), defined by Rotmans (2001) as 'a multi- or interdisciplinary process of structuring knowledge elements from various scientific disciplines in such a manner that all relevant aspects of a complex problem are considered in their mutual coherence for the benefit of decision making'. The methodological guidance provided in this chapter is timely in view of the growing interest in building ever more complex and integrated energy models (e.g. the POTENCIA model built and operated by the European Commission's Joint Research Centre)[1] (Mantzos et al. 2017) and/or combining quantitative (i.e. model-based) and qualitative (i.e. narrative) methodologies to support the long-term energy transition (Holtz et al. 2015; Guivarch et al. 2017; McDowall and Geels 2017).

It will come as no surprise that scientific foresight is fraught with difficulties. In contrast with the clear success stories of foresight in domains such as classical mechanics, foresight in a complex domain such as energy policy is typically characterized by causal processes which are not (yet) captured and which take some time (sometimes even several decades) to be fully understood (Aligica 2003). And in the meantime, there is always the possibility of 'surprising events' or the added difficulty of free choice as a confounding factor for pure causality. Several authors have already tried to capture the transformation of science (in terms of its production, function and use) in such 'complex' environments under different denominators: 'trans-science' (Weinberg 1972), 'regulatory science' (Jasanoff 1990), 'post-normal science' (Funtowicz and Ravetz 1993) or 'mode-2 science' (Gibbons et al. 1994). Despite often significant differences, all these concepts use 'classical science' (i.e. mode-1 science, to adopt Gibbons's nomenclature) as a baseline against which changes are portrayed. Following these authors, the results of foresight exercises can no longer simply be communicated to decision-makers or wider audiences under the banner of 'scientific truth', or as a 'scientific fact'. The core problem of scientific foresight lies in assessing the solidity of the insights it provides for decision-making (Harries 2003). If foresight cannot rely on 'traditional science' and the strength attributed to its argumentation (based on empirical testing), how then can it assert its value? How can we distinguish a 'good' foresight exercise from a 'bad' one? And what exactly is the meaning of 'good' – rigorous, credible, useful, successful, anything else? Furthermore, which aspect of a foresight exercise should be judged: the data on which the exercise is based, the methodology used (e.g. is a particular method applied correctly), the results (e.g. in terms of correspondence with other foresight exercises, or coherence of the scenario storylines) or the outcomes (e.g. in terms of influence on decision-making, trust-building, building communication channels, etc.)? Who is authorized to make such judgments? The decision-makers who are supposed to make use of foresight results? Or the research community involved in producing scientific foresights? Or a wider group of stakeholders with a legitimate interest in the issue at stake?

Drawing on this background of 'mode 2-science', this chapter aims to provide some guidance on what we believe to be the most important factors to be taken into account when setting up scenario and modeling exercises as a platform for open discussion with other stakeholders and decision-makers on (long-term) energy policy in order to arrive at 'rational' energy policy decisions. This chapter is structured as follows. In Section 2, we will introduce a (probably somewhat unfamiliar) philosophical framework called 'constructivism'. In Section 3, we will give a constructivist reading of scientific foresight as a combined scientific-political practice and point out some of the main points of interest. Section 4 will give some practical recommendations on using scientific foresight as a deliberative platform. Section 5 concludes.

2 Theoretical background: constructivism

Constructivism as a theory of knowledge has a quite unfamiliar outlook on concepts such as 'reason' or 'rationality' (Heyligen 1997). Based on a pragmatic reconstruction of the use of the concept of rationality in language, some constructivists show that it represents a category for the assessment of actions and decisions (ex post or ex ante) (Rescher 1988; Batens 1992). Three types of rationality can be distinguished: the (cognitive) rationality of propositions, the practical rationality of the suitability of actions to reach aims (means/end rationality) and the evaluative rationality of the aims and purposes themselves. Any form of action (intended, proposed or actually carried out) is implicitly or explicitly supported by rationality claims in these three domains. Ideally, rational procedures would lead to conclusions or actions that everyone else would take in the given situation – at least, such a claim is often implied by a commonsense understanding of science. Rational procedures should allow us to arrive at non-arbitrary answers. As such, the concept is used to designate the invariance with respect to individual persons. But one big caveat is necessary here: the invariance with respect to individual persons does not extend to the pragmatically necessary considerations for contextual dependencies. It does not follow that the invariance also holds with respect to situations or contexts. Constructivist rationality claims therefore do not allow for contextualization but postulate it.

What do we mean by contexts? A context is any situation in which we are faced with a problem. Applied to the specific context of scientific research, this means that even if a research problem would be formulated relatively generically it would have to be answered through some form of contextual judgment. Constructivism asserts that scientific knowledge is not simply ‘a mirror of nature’. Scientific knowledge is knowledge which is produced following a certain ingenious methodology (referred to as ‘the scientific method’), but is nevertheless applied to a concrete problem and within a concrete context. In an actual situation, only a limited number of scientists will work on the problem, with limited resources (in terms of time and money) and limited knowledge. Nevertheless, they try to make these results ‘universally acceptable’ (at least to the scientific community) by some in-built characteristics. They do so by an implicit or explicit negotiation of objective, subjective and intersubjective selection criteria on which the acceptance or rejection of scientific knowledge depends (Heyligen 1997). Objective criteria reflect on the suitability of knowledge to represent the object of interest as an object (i.e. something that will not change its qualities from one context to another): one can think of criteria such as controllability, reproducibility and non-ambiguity of research (in other words, the standard criteria of empirical research). Subjective criteria reflect on the suitability of knowledge to be assimilated or internalized by an individual: utility, simplicity, and coherence with existing knowledge can all be relevant knowledge selectors. Intersubjective criteria point at the degree of acceptance of an idea within a group of subjects (e.g. peers): collective utility, expressiveness, degree of formalization, conformity with existing beliefs and authority all belong to this category.

One of the most influential constructivist theories in the field of science and technology studies is the so-called ‘actor-network theory’ (ANT) which evolved from the work of Michel Callon and Bruno Latour (see e.g. Callon 1987; Latour 1993). They describe the action of science and technology as the progressive constitution of a ‘network’. The concept ‘network’ should not be considered in the classical sense of the word. A network is a system in which both human and non-human actors (Latour uses the overlapping notion of an ‘actant’ for describing both) assume identities according to prevailing strategies of interaction. This is in line with what we wrote about contextual rationality in the above section. Scientific and technological facts do not exist separated from society and the scientific community. They only get their original meaning in a network (a context), and retain the traces of this original construction work. From one context to another, they can be ‘re-presented’ (in a literal sense of ‘being made present again’) by a ‘representative’. With this notion of ‘representation’, the ‘sphere of science’ is opened up to the ‘sphere of politics’ – i.e. both can be analyzed with the same conceptual apparatus (delegation, democracy, etc.). Latour (2004) cleverly points out the parallels between a political representative claiming to speak for ‘the public’ and an expert claiming to speak for an ‘environmental asset’: both need consultation mechanisms, negotiations and have to put ‘work’ into assuring that they faithfully represent their constituency (in the case of the politician, by organizing meetings, listening to trusted intermediaries, etc.; in the case of the expert, by attending scientific meetings, doing laboratory work, etc.); and one is certainly not more mysterious or unproblematic than the other. In ANT, the most important of these negotiations is translation, a multifaceted interaction in which actors (1) create common definitions and meanings, (2) define representations, and (3) try to persuade each other in the pursuit of individual and collective objectives. Actors share the scene in the reconstruction of the network of interactions leading to the stabilization of the system. This closure of the debate creates ‘facts’, statements that are not questioned any more.

Summing up, in a constructivist reading of ‘rationality’ this concept appears as a normative concept which can only be legitimized and renewed through contextual action. Rationality is always ‘ours’, the concept of and the criteria for rationality are constructed by and in society – without reference to some stable, ideal, non-temporal instance outside of society. However, a constructivist understanding of science does not have to lead to relativism. The pursuit of intersubjective accordance still implies a continuous touchstone and a steering mechanism for scientific knowledge. It does imply a greater sense of open-mindedness towards diverging insights.

As such, constructivism provides us with a very versatile language for describing combined scientific-political undertakings such as scientific foresight activities. In the following section, we will explore this statement further.

3 A constructivist reading of energy foresight

A constructivist reading of scientific foresight practice presents a possibly challenging perspective on the 'conventional wisdom' of scenario-based foresight and decision-making (Chermack and van der Merwe, 2003). Latour (2004) describes 'scenarization' as one step in a combined political-epistemological process. He uses the analogy of a 'parliament of things'. First, we have to select the 'actants' which will be represented at the table (in the case of energy scenarios, this could be different power plants, future consumption patterns, different resources, etc.). Then, we have to decide how these actants will be represented (a power plant could be represented by technical and economic data, consumers could be represented by a model of rational economic behavior, etc.). Next, we have to bring all of these represented actants together in a hierarchy (i.e. we have to decide to which representative we are going to trust most). This process is called a 'scenarization' in Latourian terms. Keulartz et al. (2004) have called this the task of dramatic rehearsal – i.e. the imagining of a plurality of possible futures and the way that leads to their realization. 'Dramatic' should be understood in three senses: in a concern with the interaction of personalities, a concern with a plot (e.g. creative redescriptions, new narratives), and a concern for open-endedness. Most important for our purposes is also that scenarios have to fulfill their role as 'boundary objects', spanning the domains of 'science' and 'decision-making'. The concept of a 'boundary object' was introduced in social studies of science to describe how members of different 'social worlds' manage to cooperate successfully despite their very different viewpoints and interests (Gieryn, 1995). Broadly speaking, a boundary object should be both plastic enough to adapt to the needs and constraints as experienced by the different parties involved in negotiating energy policy, while still being robust enough to maintain a common identity. Boundary objects thus acquire different meanings in different social worlds, but their structure is still common enough to more than one world in order to make them recognisable – in other words, there are a means of translation. For instance, one important function of scientific foresight exercises would be to protect scientists on one side from accusation of bias or illegitimacy (because the exercises are situated clearly as 'official' objects of advisory science, and hence no confusion with 'pure' research science is possible), while protecting policy makers on the other hand from accusations of allowing technocratic intrusions into their domain of competency. This means indicators have to fulfill conditions of both scientific and political legitimacy. Scenarios should be relevant to the concerns of decision-makers (i.e. they show possibilities for practical intervention and are politically legitimate), and if they are able to withstand scrutiny by scientists (i.e. they have to be based on an adequate analysis of the present situation and the range of possible futures implied by this present situation). In this section, we will investigate the different ways in which such 'scenarizations' can be drawn up, based on an overview of 50 years of scenario-building practice (van Notten et al. 2003) (Section 3.1), before turning to an overview of the most commonly used methods (Section 3.2) and models (Section 3.3).

3.1 A typology of foresight exercises

Within the broad confines of scenario-building practices, some family resemblances can be discerned. For instance, the difference between quantitative (modeling) and qualitative (narrative) traditions of scenario building can be underscored (the former approach prevails in the field of energy). Hybrid scenarios combine both approaches. Earlier attempts at forecasting (prediction) have proven to be largely unsuccessful (particularly in the case of long-term scenarios) and are increasingly being abandoned by scenario builders – although there still appear to exist some expectations of correct prediction on the part of policy makers. But for our present purposes, the most relevant distinction to be made is the one between primarily descriptive or exploratory scenarios – i.e. scenarios describing possible developments starting from what we know about current conditions and trends, and primarily normative, anticipatory or backcasting scenarios – i.e. scenarios which are constructed to lead to a future that is afforded a specific subjective value by the scenario developers. Neither of these two types is 'value free', since both embody extra-scientific judgments, for example about 'reasonable' assumptions. However, they differ in terms of overall purpose. That is, the choice between exploratory and anticipatory approaches depends on the objectives of the scenario development exercise. Anticipatory scenarios represent organized attempts at evaluating the feasibility and consequences of trying to achieve certain desired outcomes (or avoid the risks of undesirable ones). Exploratory (or 'what-if' analysis), on the other hand, tries to articulate different plausible future outcomes, and explore their consequences. The accent is mostly on prioritizing technological choices, the analysis is performed in a relatively closed process by technically or economically schooled experts, and the government (or administrative bodies) mostly assumes the role of client (they 'place an order' for the analysis). Finally, a distinction can be made between trend scenarios, based on the extrapolation of (perceived) dominant trends, and peripheral scenarios, which focus on unexpected developments and genuine 'surprising events'. Other common characteristics include the time scale covered (long vs. short term), the spatial scale (global, regional, local), and the subject (issue-based, area-based or institution-based). All in all, a wide variety of choices can (and have!) to be negotiated, thus opening up the necessary space for 'contextual (constructivist) wisdom' to prevail.

3.2 Foresight methods

Are scientific foresight exercises methodical, and how can we discern a 'good' method from a 'bad' one? Before answering this question, it is good to be clear about what we mean when we say we are working in a 'methodical' way. Working in a 'methodical' way implies applying a set of rules or methods to the 'object' under study. An important aspect of 'methodical' research is that the rules or methods should be applicable in more than one context. Thus, a method has an external relationship to the study object: the method has shown its use in other contexts and derives from this a certain authority. If we interpret this external relationship very strictly, this clearly conflicts with core constructivist insights (there is no knowledge other than contextual knowledge). However, if we see the development of scientific foresight methodology as an ongoing process which cannot be bounded by limitations of strict rigour and remain attentive to contextual variations (as Blass (2003) proposes to do), we see no reason to reject a methodical approach to future studies. The lack of one unified scientific foresight method is not a problem. Rather, the problem is that scientific foresight draws upon a number of methods stemming from different research traditions and disciplines without always being very candid about the inherent limitations of these methods. Therefore, we will try to address this aspect in the next few sections.

The participative approach

The participative approach includes all methods which involve people (experts, decision-makers, stakeholders, or laypeople) outside of the core research group developing the scenarios, either in the fact-finding or the evaluations stages of scenario development. According to van Notten et al. (2003), expert input is more and more complemented by stakeholder input in today's scenario development projects. Numerous participatory techniques exist: focus groups, citizen juries, envisioning workshops, etc. (see e.g. Joss and Bellucci (2002)). The advantage of participative approaches is of course that qualitative information can be integrated into the scenario exercise. They also enable imagining structural changes in the issue under study, whereas models (cf. *infra*) only allow a logic of 'smooth development'. On the downside however, participative approaches suffer from a lack of theoretical foundations (or, for that matter, a lack of a common vocabulary) enabling a judgment concerning the quality of a particular participative project or the choice of the right participatory tool adapted to a specific context (Rowe and Frewer 2004). One particular participative (expert) approach which has been applied frequently in future studies is the 'Delphi method' (and one of the case studies discussed in section 4 makes use of it). Therefore, we will discuss this particular method in more detail.

Delphi method

The Delphi method was developed from the hypothesis that, in view of the many factors that might influence the future in unpredictable ways, it is best to draw upon a large group of experts for offering insights. Thus, the Delphi method consists of a formal methodology in which a large group of experts can combine their knowledge systematically and create narratives of the future. The Delphi method has a long history of application and testing (it was developed in the 1950s by the RAND Corporation). Put very briefly, the method involves an iterative questioning of experts. In successive rounds, a group of experts is asked to supply responses to a list of questions involving the future. At the conclusion of every round, the participants are given a statistical representation of all answers and may then change their views in light of what other experts believe. 'Outliers' are asked for the reasons for their 'deviant' answer. The answers are presented anonymously to eliminate the possibility of placing undue weight on the responses of persons who hold a high status within the group of peers. This process is repeated until a sufficient degree of consensus is reached among the experts.

The main advantage (compared to models which are also capable of dealing with large amounts of data – cf. *infra*) is that the Delphi method is able to draw upon 'background' or 'tacit' knowledge that is able to make sense of statistical regularities. The use of background knowledge (stemming from different contexts) is crucial in domains such as technological developments, public policy and management, where 'successful' foresight depends less on observing statistical regularities than on knowledge of behavioral regularities, institutional arrangements, intentions and preferences of relevant people, traditions, customs, fashions, national attitudes and climates of opinion, etc. (Aligica 2003). Certain 'privileged witnesses' – be they certified experts or social actors that happen to move in relevant contexts or institutional structures – are considered to be 'repositories' of this background knowledge. The purpose of the Delphi exercise is then to transform this somewhat unstructured repository of background knowledge (which likely consists of rules of thumb, analogies, metaphors, intuitive correlations, etc.) into a structured set of reliable statements about the future. Two generic questions emerge: 'How can we assure that we have drawn upon the 'right' repository (i.e. which experts should be selected for the Delphi exercise, and how should we evaluate their knowledge)?'; and 'How can we assure that the unstructured 'background' knowledge is translated into 'structured' statements about the future without losing vital knowledge in the process?'. These questions also point out the limitations of the Delphi method.

On the first question, expert bias is a well-reported issue in literature (see e.g. Tichy 2004). Expert bias may arise from various sources:

- *Availability*: experts tend to give greater weight to readily available data or recent experience, while losing sight of long-term developments;

- *Involvement*: the value orientations of an expert, often depending on the institute in which he/she is working, or the discipline he/she masters, can shape the way in which assessments are made;
- *Motivation*: experts might have a desire to influence the results of the Delphi exercise, might have a desire to appear knowledgeable, or might experience a desire not to contradict a position taken earlier, etc.;
- *Desirability of future events*: experiments clearly show that experts perceive generally desirable events (not necessarily related to their own discipline or institute) as more likely to occur;
- *Optimism*: experts tend to be over-optimistic with regard to the realization of the innovations that they are working on (e.g. with regard to diffusion time of the innovation, the competitiveness of competitors, etc.);
- *Satisficing*: experts tend to reduce complexity by closing their eyes to the fact that the introduction of a new technology entails a complex of innovations rather than one technical innovation. In particular, organizational innovations (crucial to the diffusion of new technologies) tend to be overlooked;
- *Overconfidence*: experts tend to be over-confident about their ability to make quantitative judgments.

These different types of bias do not invalidate the Delphi approach as such, but do underscore the importance of a careful selection of experts. For instance, Tichy (2004) proposes to not only use the assessments and prediction of top-experts (since these tend to be most vulnerable to optimism biases), but to use mixed panels of experts of different grades, with different types of knowledge and affiliation (business, academia, administration, lobby groups, etc.). Even then, discussion of the results should take into account the over-optimism of top-experts, since this will tend to influence the outcomes in a certain direction.

On the second question, an important limitation of the Delphi method is that it is designed to bring a disparate group of 'informed opinion holders' to a consensus about the future,[2] if only on a range of probabilities. To us, it seems impossible that any panel of experts correctly identifies the 'winners' and 'losers' (e.g. with regard to energy technologies) of the future. Even if a Delphi exercise 'officially' claims not to do so, it is clear that the set-up (involving a panel of top-experts) serves to influence decision-makers in precisely that way. Rather than seeking consensus, we believe it would be more valuable to trace different paths and fully articulate the differences of opinion. People known for their different ways of thinking should be granted the possibility to provide challenges to existing assumptions and provide novel insights. By inviting these people to comment on the results of a Delphi consensus and on how they believe current perceptions shape scenario stories and the supporting set of assumptions, one could learn valuable lessons. These insights should push the taken-for-granted views.

3.3 Foresight models

Models can be classified according to different criteria.[3] The following terminologies are very often used (Boulanger and Bréchet, 2003):

- 'Top-down' and 'bottom-up' models
- Neo-Keynesian models and neo-classical models
- Econometric models
- Partial equilibrium and general equilibrium models
- Simulation and optimization models.

Any model is a simplified abstraction of the real world. In constructivist terms, it will only allow the entry and representation of 'actants' on very strict conditions. A model determines a process of making entirely by the categories of means and ends. A tool or instrument (e.g. a mathematical code) is the realization of the model. The model not only precedes the construction process, it also survives it.[4] For people who are not familiar with models they look as black boxes. In this section we will try to explain some basic principles of different types of models and identify the limitations of different modeling approaches. We will focus on bottom-up (technical) models and top-down macro-economic approaches (in view of the cases we will discuss).

Technical bottom-up models: simulation and optimization

A bottom-up approach is easily understood as details of individuals/firms/technologies are simply aggregated in a similar way as an accounting system. Usually, bottom-up models are not dealing with the whole economy, but only with some particular aspects which are modeled in great detail like: the energy system, the transport system, etc. Bottom-up models usually put a strong emphasis on the representation of different technologies. Economic aspects are modeled in three possible ways:

1. Either they are *completely ignored* (hence, only technical engineering parameters are taken into account);
2. *Basic cost accounting* aspects are considered. Investment and operational costs of technological options are taken into account, usually in a cost-minimizing framework;
3. The model operates as a *partial equilibrium* model. Partial equilibrium models compute an economic equilibrium between quantities offered and prices charged for commodities and services of the part of the economy within the scope of the model (therefore the term "partial"). These models assume that the link to other parts of the economy which are not explicitly covered is weak enough, such that feedbacks from these other parts can be neglected in the first place. Partial equilibrium models also incorporate demand price elasticities. This means that for instance increases in costs by environmental regulations do not only provoke shifts in the choice of technologies, but also shifts in the demand for products.

Bottom-up models can be used for *simulation* and *optimization* purposes. Simulation models can be represented by flowcharts, linking various processes by material and energy flows (an exogenously determined demand for steel is linked to different steel manufacturing processes, each with their own technical characteristics, emission coefficients, etc.). Optimization models also use the same type of information as simulation models and have similar structures that can be represented by flowcharts. Additional information in optimization models relates to the price of purchased energies and materials, investment and operational costs of different technologies. Alternative processes to fulfill the same demand requirements are represented as well. The total system cost is defined as the sum of all cost components in the system: cost of raw materials and primary energies, operational costs for the processes, investment cost for new capacities and possibly environmental taxes. The values for the variables (determining the processes) are determined by minimizing the total system cost. This means that, from all possible solutions to fulfill the final demand requirements, the combination is chosen that minimises the systems cost. The basic difference with simulation models is the determination of the value of process variables. In simulation models these values are determined from historical observations or based on *ad hoc* analysis, in optimization models these are determined by the optimization process. To illustrate the difference we consider the determination of primary energy consumption per energy carrier in the electricity sector. In optimization models, this will be determined by the characteristics of different technologies and the energy prices. In simulation models this will be based on historical information or on *ad hoc* analysis.

It should be clear that optimization is a *normative* approach (and this should clearly be communicated!), rather than explorative. The model tells us what should be done rather than what will be done. Further advantages and disadvantage of the optimization approach include:

Advantages

- *Transparent and univocally defined solutions*: in developing long-term scenarios (i.e. horizon 2050–2100), hundreds of parameters relating to the choice of technologies will have to be defined. Thousands of possible solutions exist to fulfill the demand requirements. Optimization will select only one without any arbitrary rules. This is particularly useful in comparing scenarios being developed under different external conditions;
- *Rational and consistent with economic theory*: the behavior of people is conditioned by social and cultural values and therefore they maybe not fully rational in the economic sense, but the rationality hypothesis is fully consistent with the economic theory. Minimization of the system costs corresponds to the solution of a free market under the hypothesis of perfect competition (although market imperfections can to a certain extent be introduced to these models, e.g. taxes, subsidies). However, the solution does not correspond to solutions when market imperfections are considered, like oligopoly and monopoly;
- *Endogenous investment decisions*: optimization allows for endogenous technology choices (i.e. the choices are determined by the model itself) in a consistent framework. This becomes very relevant in establishing long term scenarios as all existing capacities are replaced.
- *Development of conditional scenarios*: optimization models are very well suited to develop conditional scenarios. Other constraints such as environmental regulation for other pollutants or limiting primary energy supply for some energy carriers can be easily handled.

Drawbacks

- *Flip-flap behavior*: optimization will always select the cheapest technology to fulfill the full capacity needs, unless it is constrained by the user (e.g. in terms of resource constraints, imposed limits to the speed of diffusion of certain technologies, etc.). The result is that small deviations in prices can have a very strong impact on model result, especially in the choice of fuels and technologies. In reality these shifts will only occur from a certain threshold. This phenomenon is known as the flip-flap behavior in optimization models;
- *No guaranteed coherence*: bottom-up models usually ignore feedback effects of the economy (apart from price elasticities in partial equilibrium approaches). Thus, one major disadvantage of this type of models is that they do not cover the full economy, but only concentrate on particular aspects, like energy production and consumption. For this reason, the use of engineering bottom-up models does not guarantee the coherence of scenarios (but some of them can be connected to macro-economic models);
- *Temporal disaggregation level*: energy prices fluctuate over time (day by day, month by month, and year by year). When working with low temporal disaggregation (for instance five-year period) the average prices over the period is used in the model, but this will not necessarily correspond to the results obtained by introducing the price fluctuations in a model with a high temporal disaggregation level;
- *Inapplicability of the maximum penetration of the cheapest technology*: the maximum penetration of the cheapest technology (which cost optimization implies) is not applicable when relative

costs between technologies are site dependent or linked to parameters not taken into account in the optimization, which is often the case with energy demand technologies. In such cases, simulation is used rather than optimization. An advantage of simulation is also that it allows taking into account a dispersion in the cost values;

- *The 'complexity paradox'*: developed by Oreskes (2003, pp. 19–20), we can reformulate the paradox as follows: 'The more we strive for realism by incorporating as many as possible of the different processes and parameters that we believe to be relevant to the operation of the modeled system, the more difficult it is for us to know if our tests of the model are meaningful'. This leads to the ironic situation that as we add more factors to a model, its value as a heuristic instrument may decrease even as our intuitive faith in the model increases.

Economic top-down models: macro-economic and general equilibrium models

These models can be considered as *top-down* models. CGE models and macro-econometric models are covered in Chapters 30 and 33 of this handbook. For a discussion on integration of top-down and bottom-up models please see Chapter 32. They represent the whole economy as a closed system. They differentiate the behavior of different types of economic agents (consumers, producers, and government) in a consistent framework. Macro-economic (econometric) models and general equilibrium models are different in some aspects, such as the economic background, the scientific methodology, model specification and empirical verification and calibration.

A basic entry point for understanding the differences between macro-economic and general equilibrium models is the *equilibrium* concept in economics. The equilibrium concept applies for goods, services, and labor. If all markets for goods, services and labor are in equilibrium, one speaks about a general equilibrium. A general equilibrium is a very interesting concept, as well for economists as for policy makers, because general equilibrium corresponds to a situation of maximum welfare. However, the equilibrium concept is a rather static view on the world. Technological and scientific evolution are constantly moving the production constraints, thus changing the optimal quantity of labor at given price. Consumer preferences might depend on several factors such as social and cultural values which are independent of the economic context. So the real world is rather complex, and the equilibrium conditions are probably never realized, but the market clearing mechanism is constantly working thus moving the world towards a new equilibrium. From this discussion the following questions arise: 'What is the speed of adjustment towards the new equilibrium?'; 'What is moving faster, the move towards the new equilibrium or the new equilibrium itself?'; and 'Do the markets need government intervention?'

A basic difference between econometric models and general equilibrium models is how they look at equilibrium. Macro-econometric models concentrate on the disequilibrium in different markets, frequently with a special emphasis on the labor market. General equilibrium models concentrate on the welfare aspects associated to the equilibrium position.

Macro-economic models represent the economic circle: people work and earn money which they can spend, thus generating demand for consumer goods and services. The supply of goods is represented by some type of production functions, determining the amounts of production factors (employment, capital, energy) needed to produce the desired level of goods and services, based on relative prices of the production factors. Econometric models represent the economy in a system of equations, determining simultaneously the value of the endogenous variables. Frequently, reduced form equations are used to describe the behavior of economic agents. While economic textbooks describe markets by demand and supply curves and the price and the quantity of goods as the result of the confrontation of supply and demand, econometric models use behavioral equations linking prices and quantities directly to other variables in the model, without going explicitly through the system of demand and supply. The scientific methodology applied in building econometric models is highly empirical. Historical data (on yearly, quarterly or monthly basis) or cross section data (for instance data related to different world regions) are used to determine model parameters and functional specifications. Regression techniques produce parameter values and regression statistics allowing to judge the quality of equations and the statistical significance of parameters. However, econometricians will never judge the quality of equations on regression statistics only but will use economic insights (does this result make sense?) and past experience. For simulation purposes, an econometric model needs lagged historical observations and assumptions on (a few) exogenous variables.

Advantages

- Econometrical models can be used to produce autonomous scenarios, painting a *coherent* and *accurate* picture of a whole economic system.

Drawbacks

- The *simulation horizon is limited* by the methodology (typically 5–10 years). This limitation is due to reduced form specifications and the empirical way to derive model parameters;
- Econometric models usually *do not have explicit representations of technologies and technological improvement*. Technological improvement is frequently hidden in a number of constants in behavioral equations;
- Econometric models usually face *problems in simulating structural changes and shocks*;
- Econometric models have a *strong emphasis on the demand side* of the economy, assuming supply will follow automatically. This paradigm is typical for the short or medium period.

General equilibrium models focus strongly on the welfare aspects related to the equilibrium conditions of the economy. The underlying paradigm of general equilibrium models is of a neoclassical nature. Basically micro-economic theory is implemented in the modeling structure. General equilibrium models also present the whole economy in a consistent way and differentiate the behavior of different economic agents: consumers, producers and government. Contrary to econometric models, general equilibrium models represent the economy by subsets of demand- and supply equations and use a global market clearing mechanism as simulation technique. Producers are represented in the model by production functions. Production functions express the amount of output that can be produced by given combinations of different production factors. As producers want to minimise production costs, the equilibrium quantities of production factors are determined by the relative prices. Consumers are modeled in a similar way, starting from a utility function. Utility functions express the degree of satisfaction corresponding to a basket of different quantities of goods. Under the consumers' budget constraint, the relative price of different consumption goods will determine the amounts consumed, maximizing the utility. The model uses different types of parameters. Substitution elasticities appear in the production functions. These are rarely estimated econometrically. Frequently they are taken from the literature. Scaling parameters are derived in a calibration procedure so that the model reproduces the base year data.

Advantages

- General equilibrium models are typically designed to make comparative analyses of different scenarios for *long periods*. However, they are not designed to make a forecast. Indeed these

models require some type of baseline scenario which must largely be based on external assumptions for sectoral growth rates, technological progress and others;
- The *level of detail* in general equilibrium models can be very high. They can be combined with bottom-up engineering models to include a great number of sectors, processes and technologies.

Drawbacks

- The scientific methodology in general equilibrium models is *highly theoretical and deductive.* In fact, production functions and utility functions are very abstract concepts which are very difficult to observe empirically.

Conclusion on models

All models present advantages and drawbacks. It is important to be candid about this 'fact of life' in communications towards non-expert audiences. Our short review tends to show that model methodologies can become complementary to each other, depending on the type of application considered. Therefore, often a combination of methods and models becomes the best answer to quantitative modeling of long-term energy provision developments:

- *Econometric models* are *not suited for mid- (2030) or long-term (2050 and beyond) projections*, as for the mid and long term, the technical elements and structural changes can become very important;
- *Bottom-up models* are *fully disaggregated* and therefore present both the best representation of sector and region specificities for emission related variables. As they rely on detailed descriptions of the most energy intensive installations, they are totally *transparent* (at least for those who take enough time to review the often extensive databases);
- The sectoral representation of *general equilibrium models* is focused on the macro-economic variables and its *consistency* derives from the underlying economic theory;
- *Technological change* is explicitly represented in bottom-up models. General equilibrium models include some concepts of technological change in a more aggregated or general way, which is *less transparent*;
- *Direct costs* are established by *bottom-up models* for technology/reduction measures. *General equilibrium models* are better suited to analyze *indirect costs* such as effects on GDP, welfare loss, employment, government balance;
- *Bottom-up models* will provide the best operational results on the penetration of emission reduction technologies, on the impact of regulatory measures, or on the reduction potential of voluntary agreements. *General equilibrium models* will provide the best results regarding economic impacts of different types of policies, in particular on economic instruments and alternative economic assumptions such as variations in relative prices.

No modeling approach is able to overpass the very large uncertainties inherent to long-term projections. It is therefore most suitable to apply methods which clearly implement key assumptions in a transparent and coherent manner. For this task, bottom-up models, with their very fine disaggregation at the sector and/or regional levels, and sometimes at the installations level, appear as the most suitable. On the downside however, this very fine disaggregation entails building databases holding thousands of variables, which all have to be checked for validity. Moreover, it will be difficult to secure stakeholder agreement when contested parameter choices (e.g. uncertain performance data for future technologies) have to be secured. Furthermore, one should distinguish carefully between ignorance and uncertainty. Uncertainties can be usually quantified to a certain extent using probability density distributions and then be integrated in to modeling exercises by applying stochastic programming. For uncertainties you know at least the "space" of the events but it may be difficult to attach "the right number" of probability to them (but in principle it would be possible). For ignorance it is much worse: You do not even know "event space"! There is by definition nothing you can do about ignorance.

4 Methodological recommendations for energy foresight

In this section, we will set out the contours of a 'model process' for setting up a long-term (energy) foresight exercise as a communicative platform. Within the context of the present chapter, our proposal will remain largely programmatic, as further specifications will necessarily depend on the contextual needs of the moment. Therefore, our 'model process' will be set out in the form of a 'menu' of tasks or activities undertaken in a foresight exercise (see e.g. Fontela 2000), followed by a short comment on what we believe to be the essential requirements (in view of communicative purposes) of that particular task. We are not proposing that these requirements should be fulfilled in each and every case, nor that every foresight exercise should necessarily perform all the tasks outlined in the following sections. Rather, our 'menu' should be seen as a checklist, enabling the energy foresight community to reflect on the propositions and to develop a more thorough justification on the choices made in their foresight activities. Also, we are not suggesting that the tasks should be performed in a linear way – rather, we can easily imagine that scenario-building groups will oscillate back and forth between some of the tasks, in search of some kind of a 'reflexive equilibrium'.

5.1 Process architecture

Preparatory stages

The importance of the preparatory stages in setting up a foresight exercise cannot be overstressed. It is in these stages that the seeds of a common understanding are sown. Ideally, all participants in the exercise should be involved from the beginning and decide collectively on the 'rules of the game'. Leaving participants out of the preparatory stages and involving them only in the latter stages of scenario development (e.g. through 'extended peer review') could induce a perception that certain rules are imposed upon them, thus limiting the communicative outreach of the scenarios coming out of the foresight exercise. All in all, the principal aim of the preparatory stages would be to encourage the group of participants in the foresight exercise to see itself as a community whose members are committed to crafting solutions to common problems. All participants should be able to see themselves (to a maximum extent possible) as the 'owners' of the scenarios. Preparations involve:

- *Discuss the basic assumptions*: A common understanding should be reached on the basic aims of the foresight exercise (e.g. 'merely' exploring possible futures vs. making recommendations on research priorities towards policy makers; normative vs. descriptive scenarios, etc.), the intended use of the scenarios, the available foresight 'tools' (e.g. developing a common understanding on the possibilities and limitations of available mathematical models), and the management of uncertainties and surprises;

- *Discuss rules of interaction*: A common understanding should be reached on the activities that will be undertaken in the foresight exercise, the timing and sequence of steps, management of possible conflict of opinion, representation of minority points of view, etc.

Problem structuring

The problem structuring phase starts with an identification of all relevant 'actants' to the problem at hand. Such identification can be aided by drawing upon established energy system indicators, other existing scenario studies, etc. However, problem structuring should not be limited to these established 'actants'. Initially, this phase should create an opening towards a wide range of perspectives and strive to include solid trends as well as loose bits of information, perceptions, impressions, etc. Also, it is important to acknowledge the legitimacy of emotional responses. Such responses should not be dismissed *a priori* or confused with cognitive bias, motivational resistance, self-interest, rigidity, etc. Problem structuring subsequently proceeds by:

- *Structuring, selecting and summarizing perspectives for further analysis*: Participants in the foresight exercise should be encouraged to think about how the perspectives collected in a broad 'brainstorming' could be enrolled in a network (in the sense that Latour gave to this concept) (e.g. 'greenhouse gas emissions' could be an object of technical measurements, a legitimate goal of global policy-making initiatives, a factor in public opinion, etc.). In this step, one should strive for a good articulation and understanding of each of the different perspectives, so that no ambiguities will arise in the latter stages of scenario development;
- *Distinguish between 'active' and 'passive' actants*: Next, a consensus should be reached on which 'actants' will be used as 'driving forces' for scenario development, and which will be used as 'dependent' actants. In general, when defining dependent actants, common scenario practice puts too much weight on measurable values such as GDP or emissions; seemingly non-measurable values such as prevalent social habits or political movements occur – if at all – only as independent values. This phenomenon influences modeling in that we become less aware of effects on seemingly non-measurable values. Therefore, we suggest that actants which are considered to be neither very 'active' (for the time being) nor 'measurable' (i.e. these actants 'pass under the radar'), but are nevertheless deemed to be relevant, should not be excluded from further analysis. They could for instance be used to test scenario robustness against possible surprises (i.e. a 'passive' actant suddenly becoming 'active');
- If the aim of the scenario exercise is to provide 'decision joints' for policy makers, distinguish between 'steering' and 'context' variables;
- *Assessment of actants' actions*: In this step, best available knowledge concerning the different actants is sought out. Methods for assessing and measuring parameters should be explored (e.g. trend analysis), creating an awareness of different existing measurement techniques (if this is relevant), and creating an awareness for the uncertainties and limitation associated with different methods. Detailed methods for data and uncertainty management have been developed (see e.g. Craye and Funtowicz 2004). Also in this step, advice of external experts can be solicited.

Scenario building

Scenario building can then take place using the well-known technique of 'morphological analysis', which aims to explore possible futures in a systematic way by studying all the combinations resulting from the breakdown of a system. The process of 'breaking down' the system implies the definition of a set of actants, which could each influence the development of the energy system into different directions. These possible developments are formulated as 'hypotheses' or 'possible configurations'. The total number of combinations represents a 'morphological space', which must then be narrowed down to several coherent sets by formulating certain conditions ('exclusions' and 'compromises').

- *Selection of actants (driving forces, steering variables, measurement variables, etc.)*: It is likely that the problem structuring phase will yield a large number of possible actants, which would be unpractical for scenario building. Therefore, the most 'relevant' ones should be selected, if possible on a consensual basis;
- *Explore instances of 'undecidedness' governing future actants' actions*: For each of the 'relevant' actants, a number of hypotheses should be developed on its future 'behavior'. Participants should be encouraged to stretch their imagination to a maximum extent possible. From the methodological point of view it is important that the hypotheses about possible future developments are developed independently for each actant (and if possible by different persons) in order to avoid a conscious or unconscious 'predetermination' of possible constellations;
- *Develop scenarios based on several structuring principles*: The scenario foresight group could be encouraged to split into smaller subgroups, while each subgroup is given the task to devise, elaborate and defend a plausible and coherent account of how the energy system could develop as seen from the perspective of a structural principle (e.g. more energy autonomy, minimizing environmental impacts, etc.). Reasoning from particular principles, subgroups should also seek out actants from other commonwealths that would support their visions (i.e. compromises can be found by identifying actants which could 'work together'). Subsequently, each subgroup should be given the opportunity to question the other subgroup's reasoning by identifying 'exclusions' – i.e. incompatible pairs of actants;
- *Develop scenarios on the basis of compromises between different structuring principles*: Based on the 'compromises' and 'exclusions' identified in the previous step, coherent scenario narratives can be developed. The most important combinations (in view of coherence) are those which include the largest possible number of compromises. This task is preferably assigned to professionals who have not been involved in defining the input.

Comparison, evaluation, and policy recommendations

This last step involves an evaluation of scenario results and (possibly) the formulation of policy recommendations.

- *Use formal mathematical modeling tools where applicable*: Wherever possible, quantification of scenario results should be a goal. Certainly for energy systems this will normally be a requirement, since most stakeholders will also rely on technical-economic parameters and arguments to support their positions;
- *Translate scenario assumptions into policy instruments*: It could be useful to explore which policy instruments would be congruent with a particular future vision. This will help participants to commit to the legitimacy, in principle, of different policy instruments. Participants should also be encouraged of course to think about difficulties of using a certain policy instrument within the logic of the different scenarios;
- *Derive policy recommendations*: If this was set as the aim of the foresight exercise to begin with, results of the previous step can be used to formulate recommendations for policy makers. Such recommendations should however be based on common principles, which

should be defined from the outset of the foresight exercise. Like candidate principles are for instance: 'robustness' (i.e. a 'good performance' of the policy measure under different scenario assumptions), 'precaution' (i.e. avoiding possible serious impacts or irreversibilities), 'economic optimization' (i.e. selecting policy measures on the basis of welfare costs), etc.

- *Communication to wider audiences*: All findings of the foresight exercise should be summarized into an understandable format for lay audiences. This task could be assigned to communication professional – e.g. science journalists.

5 Conclusions

We have stressed the crucial role of long-term scientific foresight exercises not only in support of the development of energy strategies but also as tools of deliberation and communication. This belief is founded not only in the urgency of some of the global (energy) challenges facing us (a staggering increase in global economic output, resources under continuous pressure worldwide, rising inequalities, etc.), but also in the existence of very different and often contradictory views about how energy systems operate and interrelate with other developments, and consequently, how they could or should be managed. Nevertheless, good intentions can never be a substitute for thoughtful reflection in order to enhance the chances of successful communication. In this chapter we have provided some guidance on how scenario exercises can be designed to meet the challenges of developing sound scientific advice based on intense stakeholder deliberations in such uncertain and complex contexts. In particular, we have shown how a link can be drawn between constructivist perspectives on science and technology and scientific foresight in the hope of informing the process of scenario-based planning and communication. Our constructivist reading suggest that 'positivistic' approaches to foresight – suggesting that the 'true futures' are out there and the job of the scenario exercise is to find it – should be rejected. Instead, scenario-based foresight can be approached from a constructivist perspective and still produce results. Scenario analysis can play a major role in addressing the core question of how to scan the future in a structured, integrated and policy-relevant manner. From the review of scientific literature discussed in this chapter, we offered some guidelines of good practice for the benefit of the energy foresight community. Keeping in mind however that a real foresight exercise should be tailored more specifically to the practical needs of the problems being addressed in a particular context. There can be no 'one-size fits all' approach to the complex challenge of developing long-term energy strategies.

Notes

1 https://ec.europa.eu/jrc/en/publication/potencia-new-eu-wide-energy-sector-model.

2 We are referring here to the Delphi method in its 'purest' form, that is the classical technology Delphi. Other applications exist which do not imply any prediction of the future: the policy Delphi and the decision Delphi.

3 The following section is mainly based on ECONOTEC/VITO (2005).

4 We draw here upon the distinction introduced by Arendt (1958) between 'instruments' and 'works of art'.

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