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Strategic Environmental Consideration of Nuclear Power Through Comparative Evaluation of Energy Options

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The key topic of the paper is comparative evaluation of various energy options. It is treated from the strategic planning and assessment points of view and is supported by a discussion of multi-objective decision making. Environmental considerations are foremost. A basis for the comparative evaluation is condensed information from 296 selected worldwide studies of the sustainability of Renewable Energy Sources (RES) and other technologies as presented in IPCC report from 2011. Conclusion is that nuclear power looks better than other options when evaluating broader environmental context of the technologies. Social and economic aspects were not considered due to lack of information in the studies. The comparative evaluation was supported by an expert system named DEX–Decision Expert.

1. Introduction

Comparative information about the environmental impacts of various energy systems can assist in the evaluation of energy options and consequent decision making. Over the last thirty years a number of studies have attempted to quantify such impacts for a wide range of energy sources. These estimations have taken different approaches, from impacts of fuel acquisition through to waste disposal (IAEA, 2000). Some recent studies on the potential role of nuclear power in contributing towards a future sustainable energy system also offer a decision-support framework that can be used by decision-makers and other stakeholders to gain an understanding of sustainability issues related to nuclear and other electricity options and to make informed choices, e.g. UK Government Department of Energy & Climate Change study (DECC, 2010), SPRIng study Assessing the sustainability of nuclear power in the UK (SPRIng, 2011), World Energy Council report on Energy Sustainability Index for 93 countries (WEC, 2012), IAEA report Nuclear Power and Sustainable Development (IAEA, 2006), OECD NEA report Nuclear Energy in a Sustainable Development perspective (NEA OECD, 2000). These studies, either country specific or international, put emphasis on multi-objective evaluation of the energy alternatives, and guide decision-makers towards open and participative decision-making process. The key argument is that sustainable development is about equity and participation as much as it is about science and technology.

2. A brief discussion on energy planning, assessment and decision-making

In a very general terms, when one gets involved in planning it is strongly recommended to consult the theoretical background to the topic and its integration with strategic evaluation. As an initial and philosophical reading one may choose Nigel Taylor's article Planning theory and the philosophy of planning (Taylor, 1980) where the author provides an overview and explanation of the relationship between values and facts and the logical distinction that can be made (and thus between ethics and knowledge).

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2.1 Key parties involved

The planning process is aimed at seeking the preferred supply and demand side options and the strategies for solving present problems in the power sector (e.g. supply shortages, high costs with unclear externalities, non-compliance with environmental policy goals and regulations). This requires, at the same time as addressing various objectives of the electricity utilities, collaboration of the various actors in the energy and other economic sectors and, more generally, all interested and affected parties (IAPs) (IAEA, 1999). Decision makers have the key responsibility for identifying the problems needing solution and for choosing from among the possible solutions derived by decision support studies, according to their own values and priorities, as well as the political and social context. Interested and affected parties have an important role to play in the overall process, and their viewpoints and concerns have to be recognised and taken into account, insofar as is feasible, at each step, starting at the very beginning. The role of electricity analysts/planners is to formulate the decision maker's problems in an analytical framework and to derive alternative possible solutions, taking into account relevant constraints (e.g. emission limits, public health goals, land-use interests) imposed by regulators and concerns expressed by IAPs (IAEA, 2000).

2.2 Planning and strategic assessment

Sustainability appraisal (SA) has recently emerged as a policy tool whose fundamental purpose is to direct planning and decision-making towards sustainability. Its foundations lie in well-established practices such as strategic environmental assessment (SEA), applied to policies, plans and programmes, and in project environmental impact assessment (EIA). The distinguishing feature of sustainability appraisal, when compared with others, e.g. SEA, is that the concept of sustainability, not just the environment, lies at its core. However, comprehensive SEAs also deal with all three components – environment, economy and society - in a balanced way (Therivel, 2005). No matter which type of assessment is applied at the highest planning level, either SA or SEA, its aim is to provide answers in a comparative manner and to assist in the process of identifying the most suitable alternative, e.g. energy option.

2.3 Comparative evaluation approach and its indicators

Multi-objective analysis (MOA) is aimed at facilitating comprehensive and consistent consideration, comparison and trade-offs of economic (financial), supply security, social, health and environmental attributes of selected alternative energy options or systems (could also be technologies for electricity production). MOA is expected to assist in the systematic evaluation of options according to multiple objectives/criteria which are different and which may not be measured on an interval (or even ordinal) scale. It should be understood that MOA is not primarily a method that can be used to derive impacts, but rather a method that places different types of impact on a comparable basis and facilitates comparisons between impacts originally estimated and expressed in different units (IAEA, 2000).

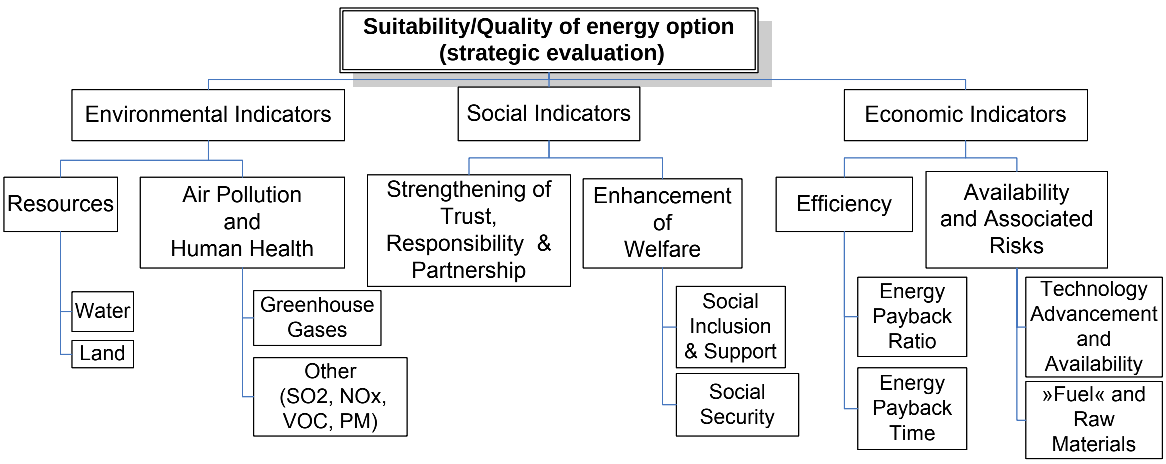

Figure 1: A schematic presentation of a multi-objective model (decision tree structure) used in comparative evaluation of electricity generation technologies by DEX

3. Comparative evaluation of energy options

3.1 Approach, methodology and tools

An example describing how to make a comparison of different energy technologies is provided below. The approach, which has been applied was strategic environmental assessment combined with multi-objective analysis supported by decision expert system DEX (Kontić et al., 2006). Operational basis for the evaluation was a model (a decision tree) as presented in Figure 1. The model builds on evaluation indicators as presented in Table 1. Technical data were collected from 296 studies (out of 2,165 references that passed screens as described in Eurelectric RESAP (Renewables Action Plan) Summary Report (Eurelectric, 2011), and the IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) (IPCC-SRREN, 2011).

DEX is presented in detail in Bohanec (2003) where the concepts and philosophy are explained based on examples. Utility functions in DEX are adjusted to qualitative variables and therefore represented by decision rules, which are usually given in tabular form. An example is provided in Table 2 where decision rules for the attribute "Environmental indicators" are presented (see also the sub-tree "Environmental indicators" presented in Figure 1; the two sub-attributes are: 1) Resources, and 2) Air Pollution and Human Health). The rules should be read as follows (see the first two rows in Table 2): if both resources and air pollution and human health are “poor”, the “Environmental indicators” is also “poor”, but if resources is “poor” while air pollution and human health is "good", then the “Environmental indicators” is “better”. It is important to note, however, that performance values and criteria for all basic qualitative variables, which are in the case of e.g., resources “Water” and “Land”, and in the case of air pollution and human health "Greenhouse gases" (GHG) and "Other (SO_2, NOx, NMVOC, PM)" have quantitative justification, similar like those presented in Table 3. Additional explanation for Table 3 is as follows: when an energy technology option uses more than 1 m^3 of water per MWh this is classified as "high" value; consequently, such technology option performs worse than the one which uses less than 1 m^3 of water per MWh. DEX uses these interpretations in utility functions for all attributes.

Table 1: A list of main indicators (to be) applied in comparative multi-objective assessment

Main (aggregated) indicators	Goals/objectives as a basis for specification of sub-indicators and development of the evaluation criteria
Cost/Value	Development of competitive (least cost) electricity production
Supply Reliability	The energy payback ratio; energy payback time
Economic/Technological Advancement	Development of an electricity system expansion plan that minimises greenhouse gas emission
Welfare of local and regional communities	Enhancement of the welfare of local communities; growth of social capital across region
Environmental and Health Impacts Risk/Uncertainty Management	Protection and improvement of the health of all residents and workers (good access to health care, reduced health inequalities, affordability of safe and quality nutrition, access to better and effective education, availability of recreation zones/infrastructure, nursing/work/social inclusion for elderly people, clean and healthy environment, safe urban areas, long-term land-use planning, etc.

Compared to traditional multi-attribute modelling methodologies (Triantaphyllou, 2000), which use numerical variables instead of qualitative ones (Boroushaki and Malczewski, 2010), DEX is more suitable for less formalized decision problems. It also applies more user friendly expressions in the context of defining the decision rules.

Table 2: Decision rules for aggregated attribute "Environmental indicators"

Resources	Air Pollution and Human Health	Environmental indicators
poor	poor	poor
poor	good	better
medium	poor	poor
medium	good	very good

good	poor	poor
good	good	very good

Table 3: Performance values of qualitative variables for evaluating impact to water as a natural resource

Attribute's qualitative variables as quantitative criteria	Performance values in terms of impact
Total water consumption exceeds 1 m^3/MWh	High
Total water consumption less than 1 m^3/MWh	Low

Note to Table 3 – in the process of defining utility functions it is needed to specify what the particular performance values mean. Related to evaluating impact to water as a natural resource it was adopted that the value "high" gets negative meaning and the value "low" gets positive one. Based on these definitions (increasing or decreasing utility functions) DEX could properly combine the performance values and decision rules when it came to aggregated attributes and eventually final evaluation of the energy options at the tree root. The approach has been consistently applied throughout the decision tree.

4. Results

Results of comparative evaluation show that nuclear and hydropower outperform other options (Figure 2). Figure 2 also indicates that bio-power may take two final scores, "poor" or "reasonable". This is due to any of the values for "Efficiency" – see the second column of Table 4. Table 4 is a condensed overview of the alternatives, the model of the comparative assessment, and the results of evaluation; in the first column the decision-tree in linear form is presented, while in subsequent columns the performance values for basic and aggregate attributes are given, respectively.
In terms of data on which the evaluation is founded it is important to note that the IPCC - SRREN report (2011) is lacking the information on social and economic implications of energy systems. Consequently, the evaluation is not comprehensive but rather incomplete or even weak in terms of sustainability.

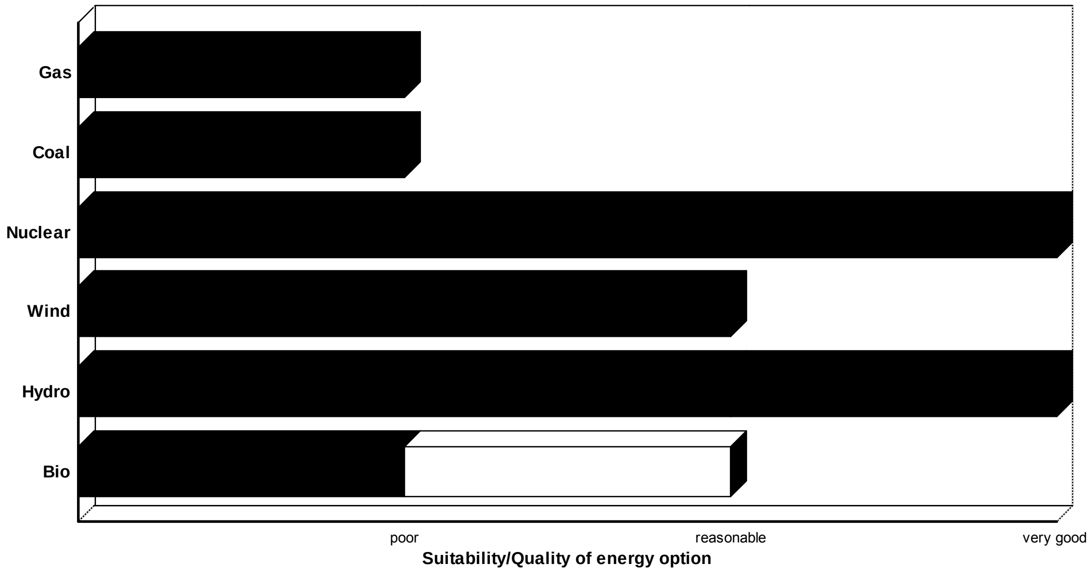

Figure 2: Results of comparative evaluation of energy options - integral scores as presented in Table 4 (see second row of the Table)

5. Conclusion

There have been a number of approaches and tools developed in order to assist in evaluating and implementing sustainable energy strategies. Application of DEX showed that 296 worldwide studies on the environmental impact of energy options are supportive in terms of nuclear and hydro energy. Such a result may seem generally valid and applicable, however, each country/government needs to make its own choices also based on data available at local and regional level, and considering actual value system together with public opinion. Neither the value systems nor public opinion are stable and may become a subject of sudden change as experienced after Fukushima accident in 2011, e.g. in Germany. This is an important factor, which requires iterant consideration of both sustainable energy goals and further development of tools aimed at supporting decision-making processes for their achievement.

Table 4: Summary on the decision tree, qualitative variables, performance values of the attributes for each of the alternatives compared, and results of comparative evaluation in terms of suitability/quality of energy option

Decision tree attributes, see Figure 1	Compared energy options Bio	Hydro	Wind	Nuclear	Coal	Gas
Suitability/Quality of energy option	*poor; better*	*better; very good*	*better*	*very good*	*poor*	*Poor*
Environmental indicators	very good	very good	better; very good	very good	poor	Poor
• Resources	medium	medium; good	poor; medium	medium	medium	Medium
o Water	low	*	*	high	high	Low
o Land	high	low	high	low	low	High
• Air Pollution and Human Health	good	good	good	good	poor	Poor
o GHG	low	low	low	low	high	High
o Other	low	low	low	low	high	High
Economic indicators - Efficiency	*	medium; high	high	high	low	Low
• Energy Payback Ratio	*	high	high	medium	low	Low
• Energy Payback Time	*	*	short	short	medium	Low
Economic indicators - Availability and Associated Risks	less-reliable	reliable	less-reliable	reliable	reliable	less-reliable
• Technology advancement	high	high	reasonable	high	high	high
• "Fuel" and raw materials	less-reliable	reliable	less-reliable	reliable	reliable	less-reliable

* any of the values

Nomenclature

DECC – Department of Energy and Climate Change
DEX – Decision Expert
EIA – Environmental Impact Assessment
IAEA – International Atomic Energy Agency
IAPs – Interested and Affected Parties
IPCC – Intergovernmental Panel on Climate Change
MOA – Multi-Objective Analysis
OECD NEA – Nuclear Energy Agency of the Organisation for Economic Co-operation and Development
NPP – Nuclear Power Plant

RES – Renewable Energy Sources
RESAP – Renewable Energy Sources Action Plan
SA – Sustainability Appraisal
SEA – Strategic Environmental Assessment
SRREN – Special Report on Renewable Energy Sources and Climate Change Mitigation
WEC – World Energy Council

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