Integrated Assessment
2003, Vol. 4, No. 3, pp. 205–213

1389-5176/03/0403-205$16.00

Creating an Energy System that we Want but don't Know Yet, Using Integrated Assessment, Transition Management and Multi-Criteria Analysis

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ABSTRACT

Within the last decades, environmental problems associated with fossil and nuclear power production and utilization have become manifest and require remedial actions to be taken. The development of Renewable Energy Sources (RES) seems to provide a promising alternative for a sustainable approach to energy utilization. However, the diffusion of RES faces a number of economic, institutional, social and technical obstacles. In this paper it is argued that a novel planning framework that combines, in a structured way, Integrated Assessment (IA), Transition Management (TM), and Multi-Criteria Analysis (MCA) could aid a potential transition towards a more sustainable energy system with a significant RES contribution. After highlighting the major features of these frameworks and their interconnections, we provide insights relevant to the main structural elements of the new frame. Innovative aspects include the time varying nature of the weights of the evaluation criteria, the integration of different temporal and spatial scales into the analysis, the appropriate treatment of uncertainty, the involvement of a diverse audience of Decision-Makers (DMs) with different values and preferences and the incorporation of learning elements. A case study is used to disclose the ramifications of the proposed approach.

Keywords: Energy system, Renewable Energy, Integrated Assessment, Transition Management, Multi-Criteria Analysis.

1. INTRODUCTION

Contemporary energy planning is very much a technocratic, top-down, non-participatory activity based on a rather limited set of narrow criteria. It is undertaken by energy utilities and governmental institutions whose foremost concerns are market costs and reliability, criteria that favor the use of conventional fuels (coal, oil, natural gas, and nuclear) with all the well-established, environmental and social problems associated with energy production, conversion and use. The liberalized energy market seems to amplify the importance of the costs and reliability factors, which favors fossil fuels, although it may lead to a reduced use of coal.

If a transition from the current state to a new, more environment-friendly and sustainable energy system is to be envisaged, this will require that different planning frameworks be developed and adopted. Under this agenda, innovative planning initiatives ought to take into account, among others, multiple criteria, different perspectives, values of a diversity of stakeholders (political DMs, businesses, Non-Governmental Organizations, regional authorities, investors – all actors involved), decentralized bottom-level decision-making and short-, medium- and particularly long-term horizons. This is not considered to be a sufficient but only a necessary condition for a shift towards a stable new paradigm of global energy system.

In this work we propose a novel planning framework organized through a new approach structured with three complementary tools: Integrated Assessment (IA), Transition Management (TM), and Multi-Criteria Analysis (MCA). IA provides the necessary top-down and bottom-up analysis of complex, socio-technical problems, TM offers a model for managing the transition from the existing system to a new one that is more environmentally and socially sustainable in a stepwise manner, using policies attuned to the circumstances of each transition stage, and MCA establishes the qualitative and quantitative framework, which not only brings into the

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decision process all stakeholders, but supplies the temporal and spatial varying nature of criteria and their corresponding weights. It is this combination that gives to our analysis an innovative planning perspective that is considered absolutely necessary when addressing complex, time-varying, multi-participatory systems under transition.

This paper proceeds as follows: In the next section we highlight the main notions of contemporary energy planning and we stress the need for altering this practice if society wants to move from the current fossil fuel dominance. Next, Integrated Assessment, Transition Management, and Multi-Criteria Analysis are outlined, and it is argued that MCA can assist the penetration of RES through integrated assessment actions under an energy transition regime. Moreover, we underpin the major characteristics of this novel energy transition management framework. Innovative aspects include the time varying nature of the weights of the evaluation criteria, the integration of different temporal and spatial scales into the analysis, the appropriate treatment of uncertainty, the involvement of a diverse audience of Decision-Makers (DMs) with different values and preferences and the incorporation of learning elements. In section 4 a case study is used to illustrate the applicability of the proposed approach and we finally end up with discussion and conclusions.

2. TRADITIONAL ENERGY PLANNING

Traditional energy production is based on fossil fuels, mainly coal, oil and gas with a small input from nuclear, and is characterized by the lack of sustainability. It has lead to increasing environmental pressures and is the main culprit for the greenhouse gas emissions with yet unknown but potentially very harmful consequences for human welfare and the earth's eco-systems. This model has served well the post-war global needs for the industrialized nations to accelerate their economies and dominate technologically the era, but needs to be aligned to changing circumstances of environmental degradation, climate change, depletion of fossil fuels, national security, and local sustainability demands. It seems that the resolution of these issues and particularly of global warming is highly interwoven with the ability of policy makers to initiate a shift away from contemporary hydrocarbon-based energy technologies.

There are many alternative sources of energy, so the real problems are the reluctance of the current regime (markets, infrastructures, institutions) to implement these alternatives and the barriers (regulatory, technological, economic) for the development of these alternatives. Cost-effective proposals, such as higher-efficiency power generation and demand-side management are likely to serve as immediate ways of reducing greenhouse gas emissions, although new generating technologies that do not depend on conventional fuels will need to be promoted and sustained to meet long-term goals [1]. Hence, there is a call for a sustainable energy system even though it is still unclear what sustainable energy is; that has to be discovered. It will most likely involve significant changes to new energy carriers, e.g. the use of hydrogen especially in transport (with the hydrogen produced onboard from methanol or elsewhere using renewables, or fossil fuels), energy demand management, and extended use of electricity from RES. Furthermore, a sustainable energy system must include diversity in order to be in a position to deal effectively with local demands and circumstances.

A new task for planning will be to help discover a sustainable energy system and make an active contribution towards its development. This calls for a different approach in which planning is used not only for achieving predefined outcomes, in terms of energy capacity and reduction of pollution, but also for learning about sustainability visions. This implies both top-down and bottom-up approaches, which work to include perspectives from citizens and businesses. The emergent approach to energy planning is therefore far more complex than the static traditional approach. The combination of professional expertise, scientific methods and well-defined targets can no longer, on their own, ensure an efficient and effective planning process. Particular tools are needed to tackle problems occurring at the interface between short and long term perspectives, objective and value-driven approaches, quantitative and qualitative information, and certain and uncertain environments.

This paper outlines a new type of planning, which has learning-for-sustainability as an important objective, while meeting immediate goals. There are two types of learning here: learning about sustainability visions, which is a national even international concern, and learning about best solutions to be used at the local level at any given time, which is more often a local concern.

As a result, policy evaluation proceeds as a learning course of action and is typically very dynamic. Decisions concerning the political relevance of issues, alternatives or impacts may exhibit sudden alterations, thus requiring a policy analysis to be flexible and adaptive in nature. This is the reason why policy should have an iterative character, and why policy evaluation and flexible goals are important. Planning and evaluation thus proceed simultaneously. Such a new model for planning is greatly needed. In the next section we describe such an approach.

3. THE NEW APPROACH UNDER THE ENERGY SYSTEM PERSPECTIVE

At this point, we introduce a new energy planning initiative that combines three conceptual frameworks: Integrated Assessment, Transition Management, and Multi-Criteria Analysis. It is argued that these conceptual frameworks could exhibit a complementary nature when applied to energy planning with IA mainly supporting a spatial integration module, TM providing the temporal integration dimension and MCA acting as a coordinating and organizing hub. This novel approach may well aid a potential transition to a more sustainable energy system. Accordingly, after highlighting the major features of these frameworks and their interconnections, we provide insights relevant to the main structural elements of the new frame.

3.1. Integrated Assessment

Integrated Assessment can be described as "*a structured process of dealing with complex issues, using knowledge from various scientific disciplines and/or stakeholders, such that integrated insights are made available to decision makers*" [2]. IA emerged as a new field in the global change research area, although it is also used to address local and regional problems. It incorporates both top-down and bottom-up approaches, which enable different issues and perspectives on these issues to be taken into account, analysed and synthesized in a coherent way. The goal of IA is to supply decision makers with new information, so that they can make better decisions. Furthermore, it offers an opportunity to develop a coherent framework for testing the effectiveness of various policy strategies, and estimating trade-offs among different policy options. But above all, the essence of integrated assessment is to offer an organized way of integrating knowledge across singular disciplines [3].

IA deals with complex issues. Several factors drive this complexity. Often, the issues are related to several domains: ecological, social, cultural, and economic. Processes in these domains tend to have diverging time scales. Some processes are rapid, while others take many years, decades or even centuries. Something similar holds for the spatial scale. Some effects are local, while others are regional, national or even global. Additionally, in the issues IA deals with, many individual and organisational actors are often involved, ranging from individual consumers to companies, NGOs and governments. Intricate feedback mechanisms often take place between these actors.

IA frameworks are characterized by a multidisciplinary decision-making process, the mutual learning of the stakeholders in the process of decision-making, and the integration of a variety of stakeholders, scales (temporal and spatial), disciplines and models [4]. Moreover, the uncertainties when considering energy-environmental management issues require an explicit treatment. Integrated Assessment states that some of these uncertainties are irreducible and that this irreducibility should not be obscured, but rather be a central issue of the assessment.

We can differentiate between three spatial levels: the local (project), the regional (prefecture) and the national and international (country–global). There is increasing awareness that economic growth, social development, and natural resource use are highly interrelated within and across these levels. An important issue is that different indicators, measuring the performance of policies, dominate within each different spatial level. It is up to the planning process to develop and establish this varying nature of the indicators. In the case of energy planning, evaluation criteria for integrated assessment comprise, among others, economic, environmental, resource availability, social, risk, technical, and cultural issues. The indicators measuring the criteria differ due to the special conditions prevailing at each spatial level. For example, the environmental impact criterion could be assessed as comprising of waste generation, water usage and discharge, landscape change, biodiversity loss, local air pollution, aesthetic, etc. issues as far as the project level concerns, while it could incorporate regional energy and environmental planning matters (land use patterns, conflicts with traditional life-style, transport networks, regional infrastructure development, etc.) at the regional level, and CO_2, ozone layer, and acidification reduction potential at the national–international level. Namely, when evaluating policy options there exists a need for deciding *what is relevant* for the representation of the real-world entity described, i.e., the selected criteria, *what is important*, i.e., the criteria weights and *how the selected criteria can be measured*, i.e., the relevant indicators.

These attributes are essential components of every decision problem that is structured around a multi-criteria module. As we will show, MCA can aid in structuring integrated assessments of such complex subjects. As a result, spatial integration under an IA framework could be achieved. In addition, multiple standpoints must interact in a meaningful manner to support robust decision-making. This is a major challenge for IA, which lacks such tools. The iterative and interactive nature of MCA methods allows for social learning processes to be established, thus, also providing an appropriate tool for letting a divergence of values to interact in a constructive way.

3.2. Transition Management

Transitions are transformation processes in which society or an important societal subsystem changes in a fundamental way over a generation or more [5]. Transitions are the outcome of processes of co-evolution. Their management involves sensitivity to existing dynamics and regular adjustment of goals to overcome the conflict between long-term ambition and short-term concerns.

TM is a relatively new concept that focuses on the policy aspects of a transition, in the various stages, the predevelopment phase, the take-off and acceleration phase and finally the stabilization phase towards the new dynamic equilibrium, as illustrated in the following Figure 1 [6].

We can distinguish four different transition phases:

- A predevelopment phase, where/when the status quo does not visibly change;
- A take-off phase, where/when the process of change gets under way;

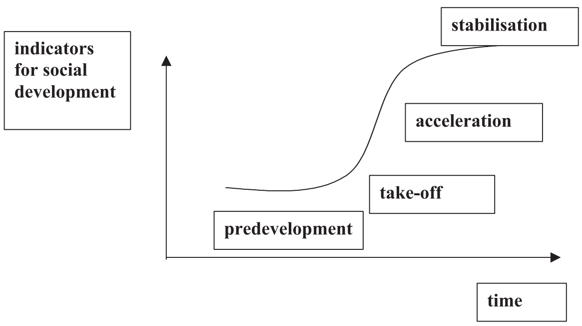

Fig. 1. The four phases of a transition.

- An acceleration phase when/where visible changes occur at a fast rate;
- A stabilization phase where/when a new dynamic equilibrium is established.

Different circumstances prevail at each transition stage and this should explicitly be taken into account in planning. Accordingly, in the predevelopment phase it is important to promote variation in order to have a broad learning process and prevent lock in to particular solutions that are sub optimal from a long-term perspective, in the take-off stage it is important to utilize well the changing impetus, in the acceleration phase special attention should be drawn to collective learning, diffusion and embedding and in the stabilization stage institutional and social aspects dominate. The whole procedure could typically span at least one generation (25 years or more) [7].

Technological change in the energy regime can take many forms. A useful way of talking about technological changes in the context of sustainability is by putting them in 3 categories (see the following Fig. 2). First is system optimization, which involves incremental changes in energy efficiency, the use of end-of-pipe technologies, maintaining the reliance on conventional fuels and especially natural gas, combined heat and power, high efficiency cars, nuclear power and only cost-effective renewables; environmental benefits are achieved without an alteration to the current production, transportation and distribution energy network. Second is a partial system redesign, which includes extended

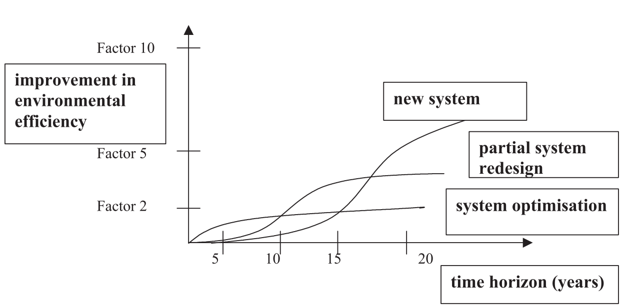

Fig. 2. Technological change and sustainability in the energy regime.

use of renewable energy in all forms (wind, solar PV, solar thermal, biomass, tidal, geothermal, etc) for electricity generation, while maintaining fossil power for transport and natural gas for heating and cooking activities; here the system is partially redesigned due to the increased introduction of renewables to the whole electricity scheme with the related diversity of supply. The third type of change is system innovation involving not only the introduction of new elements but also a change in system architecture. In the case of electricity generation, this would consist of the use of new carriers (hydrogen), the decentralized use of RES, micro co-generation, and novel energy planning schemes for decentralized electricity generation and use; here the whole energy system will change radically and must be redesigned.

Depending on social priorities in the pre-development phase any path could be adopted. But one should be careful not to traverse a path that leads in the wrong direction, causing a costly reversal. Transition management does not choose for one of the paths but sets out to learn about the different paths. Special attention is given to radical options such as hydrogen and decentralized energy systems for which there will be strategic experiments. The outcomes of the experiments would inform future policies (adaptive management). Transition management is thus indirectly concerned with paths, not directly. Markets have an important role to play but one does not rely solely on markets. The reason for being concerned with learning about long term options is that the market favours the first type of change. An example in the area of air emissions is the use of flue-gas desulphurization techniques at coal-fired power stations. This helps to reduce immediately the SOx emissions but does nothing to reduce the dependence on fossil fuels. End-of-pipe technologies and other types of technical fixes won't deal in the long run with complex social, environmental, and resource availability problems.

The real use of radical options helps to learn about the costs and sustainability aspects of these options, which is important information for developers, investors and governments. If the introduction is done in a gradual, flexible manner in an appropriate setting the costs for society are kept to a minimum, while useful lessons may be learnt.

When managing this transition with MCA instruments, this could be reflected in the weights attributed to the evaluation criteria. An increased weight for the environmental criterion, in the pre-development stage, would keep all alternative pathways open and could eventually lead to a new system. But what is MCA about? The subsequent section provides some related insights.

3.3. Multi-Criteria Analysis

Realistic goals for the integrated assessment of a long-term transition in the energy system include the articulation of differences of opinions about the topic, the identification of alternative courses of action, and the realization of possible trade-offs [8]. Multi-criteria decision-making frameworks could supply a powerful instrument for tackling these issues since they aid in defining alternatives and evaluation criteria, identifying the relevant stakeholders, providing preference data, making (implicitly or explicitly) trade-offs and finally forming draft solutions [9]. Therefore, the multi-criteria evaluation of (renewable) energy alternatives can help to achieve these goals.

MCA uses evaluations on a number of criteria to advocate an action. The supremacy of the proposed alternative is usually based on the postulation that the interests of the DM (or DMs) are adequately integrated into the assessment. Furthermore, and certainly in the context of environmental and energy planning, there exists a need for involving several groups of DMs and several fields of interest (economics, ecology, social sciences, etc). The primary task of the analyst is to establish criteria reflecting several points of view. These points of view represent the different axes along which the different actors participating justify, transform and evolve their preferences.

Unfortunately, there is no uniquely ‘‘rational’’ way to resolve contradictory perspectives, divergent values or conflicts of interest [10]. However, a consideration of the multiplicity of values (economic, environmental, social, resource availability, cultural, aesthetic, etc.) forms a crucial parameter in defining the overall sustainability vision. Moreover, the fuzziness of the set of feasible alternative actions, the absence of well-stated preferences of the members of the decision-making group, imprecise input data, the inherent uncertainty of future evaluations, and several cultural impacts impose severe consequences on the type of the decisions obtained. MCA can help address some of these issues or at least make them more transparent.

The use of Multi Criteria Analysis techniques has a long history in energy planning and provides a sound methodological framework for (renewable) energy evaluation and appraisal [11, 12]. They offer enhanced transparency for the whole process and provide deeper insights resulting in familiarizing the actors involved with the important aspects of the issue considered. They act as a guide for configuring the decision-making process, i.e. to identify the stakeholders – DMs, forming the set of potential candidate solutions, define the evaluation criteria, assessing the performance of every action on every criteria, providing preference data (explicitly by weights and thresholds, and implicitly by the whole structuring and tackling of the problem under consideration), choosing and applying a decision-making module (or even several of them and compare the results), and finally propose an action as a possible compromise alternative. An important element of MCA methods is that they decompose the problem leading to the construction of a decision matrix. This is a table containing all alternatives considered and their respective impacts according to the evaluation criteria selected. Thus, the DMs have the opportunity to address the problem on all its ‘‘technical’’ dimensions (alternatives, criteria with their scales and units) and apply their values, through the estimation of their weight attributes, to identify the proposed alternative(s) according to input.

Furthermore, MCA can provide not only the quantitative and qualitative yardstick for actually ‘‘measuring’’ past and future performance but also bring into the sight, under a democratic participatory framework, all actors and stakeholders of the energy scene. This is considered absolutely necessary due to the decentralized nature of renewable energies and the need for broader strata of the population to be actively involved in the process.

In doing so, key assumptions and choices need to be made explicit in order to enable the articulation of subjective and normative options and the underlined perspectives. Thus process transparency is really important. MCA supplies a prevailing frame for consistent and transparent policy analysis; it realizes the objective of being inter/multi-disciplinary (regarding the research team), participatory (regarding the local community) and clear (all criteria can be presented in their original form without any transformations into monetary units). Therefore it is considered appropriate for the integrated assessment of (renewable) energy under an energy long-term transition regime.

The following section tries to situate these tools under a single policy framework and reveals their complementarily and suitability for performing energy planning efforts.

3.4. The New Approach

The new planning approach is outlined in Figure 3. It weaves all three previously outlined methodologies into a new structure: The transition phases are used as periods in time when an IA can analyze and synthesize synergistic and contradicting elements, taking into account the time dimension and the different spatial levels. At the same time MCA establishes the basis for decomposing and structuring the decision exercise on which different actors with various criteria bring their particular interests.

We feel that, from a transitional perspective, the transition in energy is still in its pre-development phase. The main unsustainable aspects are: CO_2 emissions contributing to climate change, the dependence on fossil fuels with all the geopolitical risk attached, and the local and regional environmental problems arising from the combustion of conventional energy sources [7].

The organization of the proposed transition entails reconciling economic (affordability, return), socio-cultural (health, values, attitudes), technical (safety, reliability, diversity), environmental (land uses, ecological impacts, global warming), and resource (coal, oil, gas supplies) criteria. MCA methods can help to find compromise solutions and avoid a possible lock-in of ‘‘mono-culture’’ development (fossil fuels, end-of-pipe technologies).

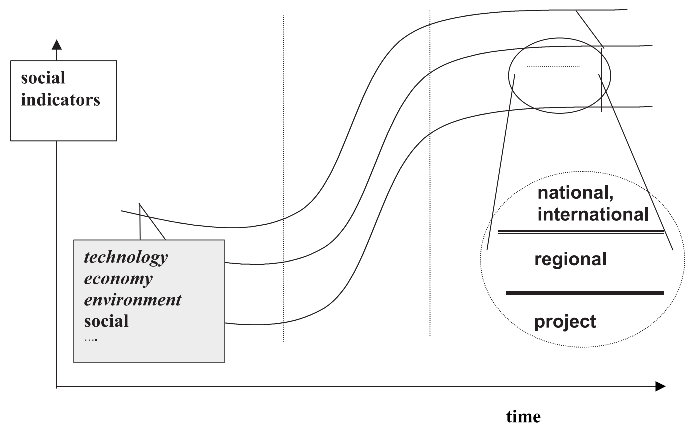

Fig. 3. The new planning approach proposed.

The management of this shift involves sensitivity to existing dynamics and regular adjustment of goals to overcome the conflict between long-term ambition and short-term concerns. The increased uncertainty associated with long-time horizons, complex technical issues and evolving preferences could be explicitly tackled by probability distributions, fuzzy sets, and for some specific families of multi-criteria techniques – e.g., outranking methods – by threshold values [13, 14].

The time varying nature of the decision criteria could be launched with MCA of energy alternatives under a transition regime. Depending on the position in the transition curve and on the objectives to be realized, different criteria and weights apply. For example, in the pre-development phase there exists a necessity of ''pushing'' the transition process and keeping all alternative pathways open. The existing energy system mainly consists of fossil fuel power generation facilities and RES activities have to compete with them under an admittedly less than free market framework. At this stage comparative integrated assessment (with MCA) of RES and conventional applications pertains. The weight of the environmental criteria, therefore, should be relatively high to declare preference towards renewables. One may say that this is an indirect way to include early in the overall evaluation some of the externalities associated with conventional power generation. Thus, it can be legitimate to exploit the weight function assignment in order to internalise into the cost of energy the externalities associated with energy usage. Such an approach has not been proposed before and it is thought that the issue needs further research. In the acceleration phase, when RES are taking-off, particular focus should be given to the local diverse impact of RES ventures. At this point different renewable energy alternatives compete depending on availability. Finally in the stabilization phase social and institutional aspects should prevail. Thus one may speculate that different criteria, weights, and alternatives apply depending on the position in the transition curve, i.e., the whole multi-criteria structuring of the decision problem is a function of time. Achieving temporal integration includes establishing interconnections between these different decision-making schemes.

The spatial integration takes place with the IA of RES. In this case it is the indicators that measure the choice criteria, which change according to each spatial level. For example, the return on the investment could be the relevant indicator for the economic criterion at the project level, while regional and national GDP measures could prevail at higher levels. At the local – project level different (renewable) energy ventures compete; at the regional level it is the specific circumstances of each area (local environmental conditions, renewable potential availability, population, infrastructure, etc.) that determine the appropriate indicators and at the national–international level the contribution of each solution to global policy objectives dominates. As a consequence, at every spatial level a different multi-criteria structuring of the decision-making application exists with policy alternatives, DMs, and indicators (see Table 1 below) being different.

Furthermore, the weights attributed to the criteria have a strong time-varying nature. In the pre-development phase the environmental criterion should be given high priority while during the acceleration the importance of the energy–resource criterion is higher giving thus priority to actions promoting renewables. Finally in the stabilisation phase it is the social and economic criteria that should be considered important.

In addition, the proposed approach can explicitly incorporate learning elements by allowing for iteration and successive evaluation in development rounds. The new insights gained are utilized to re-evaluate the criteria weights. For example, if by measuring regional conditions we observe environmental degradation trends the weight of the environmental impact criterion is increased to remedy the situation.

A general question arises on the scale of social change likely needed to achieve a sustainable energy-system.

Table 1. Criteria indicators at various spatial levels.

Criteria/spatial dimensions	Project level	Regional level	National + level
Energy	Rate of resource exploitation, tons of oil equivalent saved	Fulfil regional demand, cover seasonal variations	Imported oil reduction potential, fulfil national demand, guarantee diversity of supply
Economy	Return on investment	Regional GDP	National GDP
Environment	Waste water discharge, aesthetics	Land use, conflicts with other activities (tourism)	CO_2 reduction potential, acidification, biodiversity loss
Employment	No. of jobs created	Regional unemployment reduction potential	National employment rates
Technical	Technical feasibility	Stability of the network	Compatibility with international energy networks

The proposed frame could provide a first attempt to quantify this social amendment, as is reflected in the weights of the relevant evaluation criteria. Thus, for an energy transition to occur it is vital that IA endeavours encompass the quantification aspects that MCA brings into the exercise.

As a result, MCA methodologies can be considered as a vehicle for integrated assessment activities under an energy transition framework. Temporal and spatial integration could be launched and useful feedback mechanisms initiated. The framework is based upon iterative procedures enabling rearranging targets, objectives and policies under a dynamic approach. The whole process is quite complicated and requires a number of successive steps for a satisfactory outcome. The insights gained can be used to develop appropriate environmental and resource management policies. The framework helps to structure the thinking of the relevant actors, but is does not replace them! It merely decomposes the complexity, leading to more informed decisions.

The ramifications of such a framework i.e., the current situation – predevelopment, acceleration and stabilisation phases – are illustrated in the following example, concerning RES electricity power production.

4. CASE STUDY – THE EUROPEAN ELECTRICITY SECTOR UNDER TRANSITION

The European energy policy is expected to focus around axes that include the deregulation of energy systems, the integration of energy networks (electricity, natural gas, etc.), the globalization of environmental problems and the mobility of human resources. Currently, the European electricity system is characterized by increased CO_2 emissions, local atmospheric pollution, increased dependence on fossil fuels (with all the geopolitical risks attached), and lack of diversity of supply, which gives it an unsustainable character. Therefore, there is a growing awareness in the EU that in the long-term a structural change in the energy supply and demand system is necessary.

The achievement of a new European energy future will necessitate a close interaction between technological, economical and social issues. On the technology front new fuels and processes will be developed (hydrogen, RES, etc.). On the economy level new energy markets must be designed and implemented guaranteeing deregulation of the existing situation enabling new energy producers to participate. A move away from the classical monopolistic energy market is necessary. Finally, on the societal level education of the people is required while at the same time new participatory tools-methods should be promoted to establish transparency of public involvement.

Extended utilization of RES seems to offer an alternative able to reduce the environmental impact of the power generation sector. RES, however, provide energy to an existing structure of electricity distribution while users are still applying electricity in familiar ways. The use of renewables in a centralized system is more a process happening within power generation, than within the whole energy system [15]. A hybrid electricity production system (RES + fossil) could be an intermediate step in the transition to a more sustainable global energy system, based mainly on hydrogen and clean power generation. This transition will probably require two generations or more [7].

The proposed approach introduces a long-term energy management framework, under the above prevailing conditions. Alternative European energy futures can be assessed and their feasibility evaluated according to current conditions. The recommended framework tries to guarantee the non-exclusion of alternative energy development trails (the hydrogen economy, a clean electricity society), while achieving short-term goals in terms of emissions reduction and economic development. Moreover, social preference regarding energy issues can be mapped and the necessary organizational, cultural, social, and economic attributes, which form the contemporary situation, can be revealed, as well with their interconnections and alteration potential. Short, medium, and long-term realistic goals can be determined on top with the means to achieve them.

More specifically, the EU has an energy system that can be considered to be in the *predevelopment* phase of a transition. RES contribute around 6% of the gross EU energy consumption. In their Green Paper on Renewables the Commission sought views on the setting of an indicative objective of 12% for the contribution by RES to the gross energy consumption by 2010 [16]. This is translated into a potential contribution of 22.1% for RES in the power sector. Apparently, this is only an interim objective.

Transition Management can use this intermediate target to increase pressure on the existing energy system, and at the same time explore several alternatives through a learning process. At this stage in the transition, IA of RES tries to safeguard (with MCA) an open playing field for all potential long-term alternatives e.g., CHP, hydrogen, fuel cells, distributed generation, while at the same time providing sufficient time for their development and experience with their use. A possible way to achieve this could be the explicit adoption of higher weights for the environmental criteria. By that, policy makers could eliminate the possibility of an early exclusion of long-term alternative energy visions and avoid possible lock-in situations, as is the case with fossil technology and infrastructure development.

Later on, in the *acceleration* phase, assuming RES have already achieved a ‘‘take-off,’’ a different structuring of the problem should be initiated. Renewable energy alternatives will now be competing among themselves and the energy situation will be dramatically changed. RES will supply a significant percentage of the energy input (electricity and thermal), new energy carriers will be introduced, consumers will also be producers of electricity as photovoltaics, wind turbines, and novel building shells with PV skins are widely deployed. Our approach allows for the establishment of different indicators measuring the evaluation criteria selected. The analysis must now focus on the local environmental impacts and the corresponding weights should reflect the general environmental condition of the region.

In the *stabilization* phase, social and institutional issues are governing and employment and social cohesion criteria take the lead. Obviously, reassessing targets and preferences is an essential part of the exercise. When RES-based power generation stabilizes itself in the energy supply network, then the whole decision-making process could be started all over from the beginning, kicking off a shift to a new energy-technology paradigm. With extended decentralized utilization of RES the clean electricity based society could be now envisaged. New energy carriers could take-off since the dependence on fossil fuels has generally been alleviated and possible barriers overcome.

In all the above phases, real data comprising renewable technical potential, institutional and cultural factors, social issues, stakeholder values, economic and environmental features, resource availability, etc. can be evaluated through different temporal and spatial scales. Moreover, and for each European region, the required endeavors could be revealed that eventually lead in achieving short-term (Kyoto commitments) medium-term (substantial reduction and stabilization of CO_2 emissions) and long-term (the hydrogen economy, extended use of clean electricity) objectives. Proposals for regional and local energy development plants can be explicitly stated and their overall contribution to a future sustainable European energy scheme quantified. This can be done in cooperation with authorities and people from energy agencies and companies. Furthermore, national experience can be exchanged and enhanced, communication between the relevant stakeholders established, social preferences mapped and the organizational, institutional, and cultural barriers that prevent the adoption and diffusion of advanced and competitive renewable energy technologies effectively addressed. The final aim is the management of the evolution of the European energy system and its direction towards a sustainable pattern. The secondary objectives include:

- quantification of the social impetus and institutional changes needed to achieve a gradual energy transition to a sustainable energy future;
- mapping social preferences and comparing these on with the necessary preferences that would result in transforming the dominant fossil fuel pattern;
- revealing of possible ways to achieve several short-term (22.1% of renewables contribution to electivity production be 2010), medium term (a low emission energy supply system – 50% CO_2 reductions of current level to be envisaged in the next 50 years) and long-term (the no emission society, the hydrogen economy) targets;
- evaluating of existing national and international policy goals from a long-term transition point of view and a short-term economic point of view.

Such a management and iterative planning initiative is considered to be of particular importance, since the long-term aspects of energy planning are hardly ever tackled at a concrete and practical level. Overall, it is a long-term energy transition management framework to guide the European electricity system towards a sustainable state.

5. DISCUSSION AND CONCLUSIONS

In this paper, a novel decision-making framework for energy planning is presented. It is structured around three complementary policy agendas, namely Integrated Assessment, Transition Management and Multi-Criteria Analysis. The increased complexity of the issues involved arising from a lack of complete scientific understanding for many natural processes, the uncertainty surrounding future events, the long-term horizon needed for planning, and the necessity to include a diverse audience of DMs with multiple points of views suggests that an integrated approach can be adopted for management and decision-making. IA provides the ability to incorporate different spatial scales into the analysis by allowing for the evaluation criteria to be assessed by different indicators according to each spatial level of relevance (local, regional, national–international). Moreover, it permits several DMs to participate and stresses the need to communicate the results to a larger audience (i.e., the general stakeholders).

Transition Management specifically gives a dynamic element to our approach. It offers the time varying character of the problem formulation, by allowing a different structuring of the issues, as expressed by changes in criteria, alternatives and preferences, according to the particular point in the transition curve. Moreover it brings into the policy evaluation a learning component. The results obtained after every development round can be assessed according to the set of objectives while the insights gained may well be used to form the next evaluation endeavor.

IA and TM lack however, at the time being, formal instruments to foster their application. MCA and decision-making frameworks could provide such a function. They offer a consistent and coherent framework to gather, organize, and analyze all relevant information, thus rendering the decision-making procedure robust and transparent. They also provide a first attempt to quantify the related social changes associated with an energy shift.

By these means multi-disciplinarity is promoted, different spatial and temporal scales are taken into consideration, a diverse audience of DMs participates, uncertainties are explicitly tackled, policy focus is enhanced, and finally transparency and public participation are encouraged. This rationalization of the procedure can only add credit to the quality of the decisions made.

ACKNOWLEDGEMENTS

Financial assistance from the European Commission IHP programme, Marie Curie Training Sites Fellowships, is acknowledged. Marie Curie Multipartner Training Site coordinator: University Louis Pasteur [Laboratoire d'Economie Théorique et Appliquée – BETA, 61 avenue de la Forêt Noire, 67000 Strasbourg, France], (contract number: HPMT-CT-2000-00145). Host institution: Maastricht Economic Research Institute on Innovation and Technology (MERIT), Maastricht University, PO Box 616, 6200 MD, Maastricht, The Netherlands. The corresponding author would like to thank all MERIT staff and students for their support and especially Corien Gijsbers and Silvana de Sanctis.

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